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ELECTRICITY AND MAGNETISM

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AURORA BOREALIS

observed at BOSSEKOP (FINMARK) January 19th 1839

ELECTRICITY

AND

MAGNETISM

TRANSLATED FROM THE FRENCH OF

AMÉDÉE GUILLEMIN

REVISED AND EDITED BY

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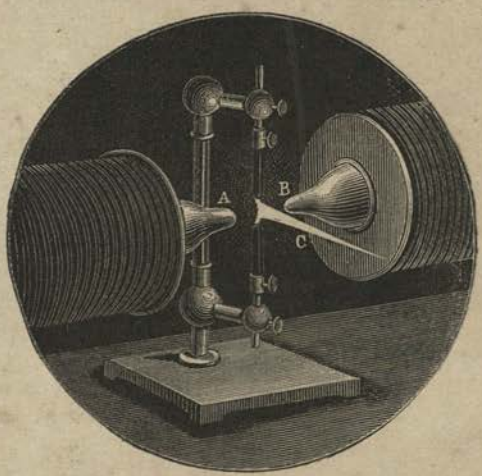

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EDITOR'S PREFACE

In presenting to the British public this edition of the popular work of M. Guillemin, which in the original French has won so wide a circle of readers, it is only fair to let the public know how far the Author and the Editor are severally responsible for the work.

Beyond revising the translation and correcting the various electric and magnetic data to the present time wherever possible, the Editor can only claim responsibility in three points. The chapters on Dynamo-electric machines and on the Telephone have been largely rewritten by him in accordance with modern knowledge. Various footnotes and addenda have been made; all those for which the Editor is responsible being distinguished by being enclosed in square brackets. The utmost pains have been taken to revise the text, wherever, and in particular in the earlier parts of the work, the now obsolete two-fluid theory had affected the language of the Author's text. For all else the Author is responsible. Written by a distinguished French *littérateur* for French readers, it is impossible that the book should, in its English dress, escape the charge of using here and there French modes of thought and expression. Many of the types of instruments described are those in vogue in France. To have substituted in every instance British types

would have deprived the book of some of its most characteristic features: accordingly the descriptions and figures of the original edition have mostly been retained, but the Editor has sought to supplement these descriptions by notes pointing out differences of practice where they are important.

The Editor is anxious that this work should be estimated not beyond the pretensions it makes to be a popular, simple, non-mathematical exposition of the science that now excites such general interest. It is intended for the table of the drawing-room rather than for the desk of the student, and must not therefore be judged as though it pretended to be a text-book of reference. Yet the Editor ventures to believe that he may have rendered some service to the cause of the science if by rewriting a popular account of the principal phenomena of electricity and magnetism in language which accords with the views of Faraday and of Maxwell and of all modern British electricians as to the nature of electric and magnetic actions, he has helped in however small a degree to assist toward burying the old traditions of the untenable fluid theories of electricity and magnetism.

The burden of translation of the work and of much of the revision has been borne by two of the Editor's former assistants, Mr. Colman C. Starling and Professor R. Mullineux Walmsley, D.Sc., to whom he gratefully acknowledges the services they have rendered.

The Appendices are, of course, special to the present edition. Chapter XVII., which is an addition to the text, on Transformer Systems, is from the pen of Professor Walmsley.

S. P. T.

November, 1890.

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FIRST PART

PHENOMENA AND THEIR LAWS

ELECTRICITY AND MAGNETISM.

BOOK I.

MAGNETISM.

CHAPTER I.

MAGNETS.

§ 1.—*General Phenomena of Magnetism.*

THE name oxide of iron, or magnetic oxide of iron, is given by mineralogists to a mineral of this metal which is met with in a great number of mines in both hemispheres. The chemical formula $FeO + Fe_2O_3$ shows us that this mineral consists of a combination of the protoxide and sesquioxide of iron. It crystallises in the form of octohedra, and sometimes in that of rhombic dodecahedra. Some specimens of this oxide have the property of attracting to various points of their surface small pieces of iron or steel which may be brought near them, and on account of this phenomenon they have received the name of *lodestones*, or *natural magnets*, in order to distinguish them from pieces of steel which have received this power by artificial means, and which, therefore, are called *artificial magnets*.

The more important beds of magnetic oxide, or *magnetite*, as mineralogists call it, are in Norway and Sweden, where it is found in the form of compact masses of metallic lustre; also in the Isle of Elba, in the midst of heaps of mineral found on Cape Calamita. It is also found in Auvergne, in Germany, the United States, and at Bône in Algeria. At Magnet-Cove, in Arkansas, there is a whole

mountain of magnetite, which is quarried as a regular ore of iron. The general colour of lodestone is blackish or brown, sometimes greyish; it has a somewhat metallic appearance; its specific gravity = 5·1; it is the best of all the ores of iron.

Nothing is easier than to show the attraction of iron by a magnet, whether natural or artificial. All that is necessary is to plunge it into a mass of iron filings or turnings. On drawing it out it is seen

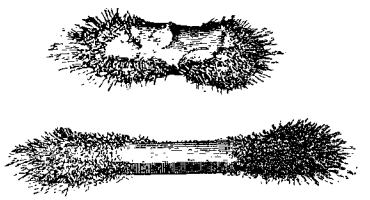

FIG. 1.—Attraction of iron filings by magnets.

that they stick to certain parts of the magnet, and are grouped in tufts more or less densely. Pieces of iron or steel, nails or needles, are drawn towards the same parts of the magnets and jump to it as soon as the distance between them is small enough.

The same property may be illustrated by using the small instrument known as the magnetic pendulum. This consists simply of a ball of soft iron suspended by a thread. If a magnet is made to approach the ball from the side, the latter approaches the magnet, dragging the string out of the perpendicular. The attraction increases much more as the distance between them decreases. Moreover, according to the law that the action is equal to the reaction, if the magnet attract the iron, the iron in its turn attracts the magnet. Thus, if a magnet be suspended so that it can move as is shown in Fig. 3, it moves when brought near enough to a fixed cylinder of iron, and turns about the axis of suspension so as to reduce the distance between them to a minimum.

Magnetic attraction, as the foregoing experiments show, is exerted not only by contact, but at a distance. We will further show that its strength is increased if the distance be decreased, and we will then give the law. Magnetic force also acts through all bodies, solid or liquid, which are placed between the magnet and the iron, and the thickness of these bodies does not, in most cases, alter the intensity of the attraction except in regard to varying the distance. If on a

wooden board, or cardboard, or porcelain, or sheet of copper, some

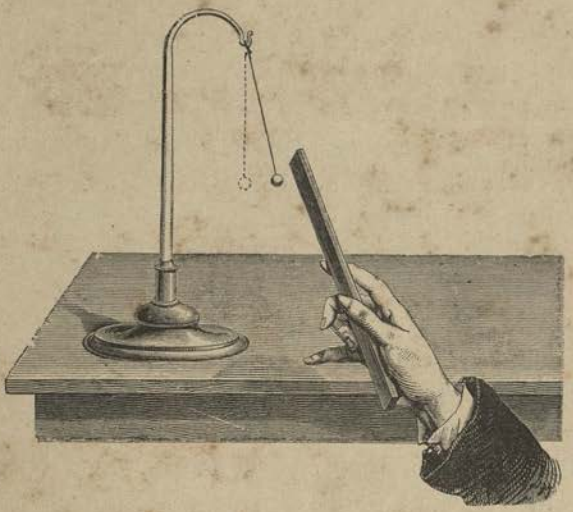

FIG. 2.—Magnetic pendulum.

iron filings, needles, or nails are sprinkled, and a magnet be moved about underneath, the filings and pieces of metal will be seen to move

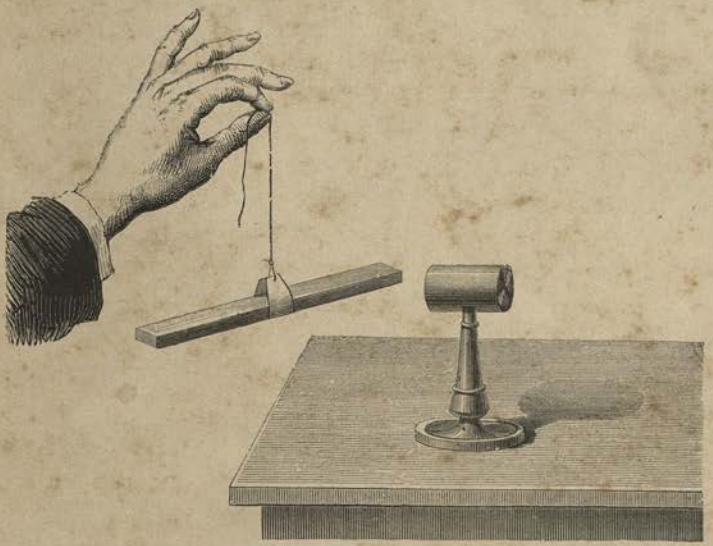

FIG. 3.—Attraction of a magnet by a piece of iron.

and change position, following all the movements of the magnet.

Magnetic attraction can also take place through vacuum as through air.

For a long time it was thought that iron was the only substance attracted by the magnet, the only *magnetic substance*, to use an expression which serves in physics to distinguish that property. Yet before the process of magnetisation was known, that is to say, before it was known how to convert a bar of steel into a magnet, when as yet the only magnets known were natural magnets, there were already samples of minerals known which did not attract iron, and yet were magnetic; that is to say, were attracted by magnets. Several ores of iron are very slightly magnetic: for example, some specimens of pyrites, and chrome iron ore and hæmatite; but none are so magnetic as the lodestone or magnetite.

Since that time several metals have been found to have the same property, such as nickel, cobalt, and chromium. Cobalt is only magnetic when free from arsenic; whilst chromium is not so at ordinary temperatures, but, according to Wöhler, it becomes magnetic if the temperature is lowered 15° or 20° below zero. By some platinum has been classed as a magnetic substance; but it now seems certain that it is only magnetic on account of containing iron, as it entirely loses this property if it is well purified.

Care must be taken not to confound magnetic substances with magnets proper. If, as we have just seen, magnets, natural or artificial, and magnetic substances attract each other, that does not say that the properties of both are the same. There is a vital difference, which we will now explain. It is that mere magnetic substances do not attract each other. A piece of soft iron, which attracts a magnet, is without action on another piece of iron, at least, if it is not near to another magnet. A piece of unmagnetised steel does not attract another piece of unmagnetised steel. It is a magnetic substance, and capable of being magnetised; but does not acquire the property of attracting until it has been magnetised. There is yet another difference on which we must dwell; it is that a piece of iron attracts at all points, whilst in a magnet the property of attracting is unequally distributed. It is at a maximum in some points and at a minimum in others. The following experiments illustrate this characteristic difference between magnetic substances and magnets.

If a magnet which has been thrust into some iron filings be

examined (Fig. 1), it is observed that the filings are not only collected more particularly at the two ends, but that the particles at some little distance from the end are also affected and are caused to arrange themselves in a special way, as if, in the part where most were attracted, there was a centre of attraction. Near the middle of the bar, on the other hand, there is a space where no filings are attracted. The extreme ends of the magnet of which we have spoken are called the *poles*, and the central portion the *neutral zone*, or *equatorial region*. The following experiment shows still better the existence of poles and neutral zone.

On a bar magnet is placed a sheet of cardboard, on which is powdered, with a sieve, very fine iron filings. The particles are then seen to arrange themselves in a regular form about the points $p\,p'$, which correspond to the two poles of the magnet and form the converging and symmetrical lines around the neutral zone $m\,m'$ (Fig. 4).[1]

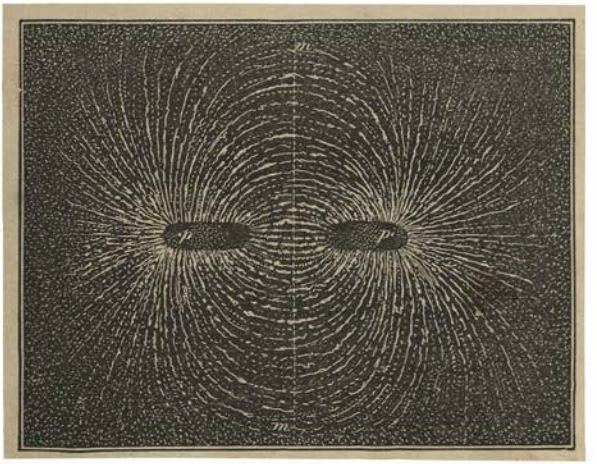

FIG. 4.—Filing-figure or "magnetic spectrum."

Sometimes a magnet has more than two poles beside the end poles, the existence of which we have just shown. Intermediate points are found where filings will stick and which are also separated from each

[1] The magnetic figures thus obtained are very useful for studying the directions of the *magnetic lines of force*, along which the filings set themselves. The details of a process originally suggested by Faraday for fixing the magnetic figures are given by Gordon as follows:—"Take a board of the same or greater thickness than the magnet, and let the magnet into it so that its upper side is flush with

other by neutral lines such as shown in Fig. 4. These points are called *consequent-poles.* It is now easy to explain the difference between magnets and magnetic substances. These latter have no poles or neutral zones: by whatever part they are presented to the magnet there is always an attractive force shown. But a magnet can only act through its poles.

In order to distinguish magnets from magnetic substances they are always spoken of as having magnetic *polarity.* We shall refer to this when we describe other experiments on the action of magnets on magnets.

Let us for the present only pick out from magnetic substances those in which magnetic polarity is capable of being rendered permanent. These then are steel, cobalt, nickel, and tempered iron. These bodies, however, if of poor quality, lose their magnetism if they are heated. Nickel loses its permanent magnetism at 350° C., cobalt at a bright red heat. This effect of heating is also observable in ordinary magnetic bodies. It is said that Newton was the first who noticed that wrought-iron was no longer attracted by a magnet if it was heated to a red heat. Barlow showed the same thing with cast-iron at a bright red heat, and we have already seen that

the upper surface of the board. Lay a smooth piece of paper over all, and fix it. Now with a sieve or 'colander' dust fine iron filings all over the paper. As each falls near the magnet it is magnetised by induction, and turns round so as to set its longest diameter in the line of force at that point. Each of these minute magnets attracts the next till a continuous chain is formed all along each of the lines of force. The board must be tapped from time to time to overcome the friction of the filings on the paper. If it be desired to preserve the curves, a piece of card with its underside gummed may be laid upon them. When the gum is dry the filings stick to the card. The magnet may be placed under a piece of glass instead of paper if preferred, in which case it will not be necessary to let it into a board. A good way to prepare these curves for exhibition in a magic lantern is to coat a piece of glass with some transparent cement, which melts on being heated. [The cement sold under the name of 'mend all' answers very well. It may be diluted with water for the purpose.] When it is quite hard, a magnet must be placed under the glass, and the filings dusted on. The glass must then be carefully carried to an oven, warmed till the cement is soft, when the filings will sink in. On removing the glass and allowing it to get cold, the filings will be all fixed in position." The editor prefers for the latter purpose a coating of gum with a little gelatine added. This is allowed to dry upon the glass, after which the filings are sprinkled over, and the figure obtained. The gum is then softened by steaming gently, when the filings sink in, and become fixed.

chromium is not magnetic at ordinary temperatures. Can we not from these facts draw the same conclusion as Pouillet—that all bodies would become magnetic if their temperatures could be reduced sufficiently? It is by experimental methods alone that this hypothesis can be sustained or rejected.[1] We shall see later that bodies become to a greater or less degree magnetic when subjected

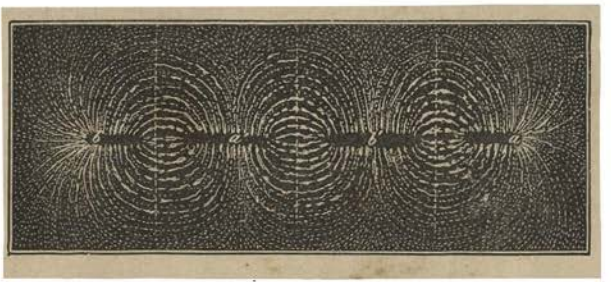

FIG. 5.—Filing-figure revealing "consequent-poles" in a bar-magnet.

under certain conditions to the action of very powerful magnets Before continuing the description of the special phenomenon common to magnets and magnetic substances, which from an unknown reason has received the name of *Magnetism*, let us give a brief outline of the history of the magnet from ancient times until the present time.

§ 2.—*The Magnet in Ancient Times.*

The fundamental property of the magnet of attracting iron was known to the Greeks towards the seventh century B.C., as it is mentioned by Thales. The Greek name for the natural magnet was λίθος ἡράκλεια, stone of Hercules, or, according to another authority, stone of Heraclea. In later ages, from the time of Plato, another name was given to the magnet—μαγνῆτις λίθος, stone of Magnesia, as it was supposed to have been found in abundance in the vicinity of both the towns of Lydia called Magnesia;[2] ancient writers do not,

[1] This hypothesis does not seem likely to be confirmed, for Trowbridge has shown that extreme cold diminishes the magnetism of magnets.—*Ed.*

[2] This opinion seemed confirmed by the name ἡράκλεια λίθος, since at that time there was a town on the borders of Lydia named Heracleia. It seems, according to Th. H. Martin, that that opinion, already well known in the time of Plato, arose from a misunderstanding; the name of stone of Lydia, λίθος λυδία, being given by mistake. Indeed, the Greeks even used the name *ironstone*, σιδηρῖτις

however, agree as to the original locality of the magnet, some say Lydia, others Troas, others, again, the Indus, or the islands between Taprobanus and the Golden Chersonese. Even down to the middle ages nothing was known of the properties of natural magnets, except that the pieces of stone attracted and held tight the piece of iron. It was not even known that a magnet, free to move, was attracted by a piece of iron. All the early hypotheses of the polarity of magnets were founded on some facts collected concerning this property, but none of them were capable of accounting for all.

Thus, according to Pliny, there was the Ethiopian magnet, which attracted all other magnets. He called another stone *Theamedia*, which had the property of repelling iron; it was without doubt only an ordinary magnet, near which the iron was brought. It was not known in olden time how to make a permanent steel magnet from the natural magnet. Yet they knew how iron was magnetised by contact, as they formed a chain of iron rings by suspending a number of them in a chain, the first one being in contact with the magnet; they knew that the power of a magnet ceases as soon as the contact ceases. Lastly, Claudian said that the magnet was strengthened by contact with iron.

In Lucretius's *Rerum Natura* there is this passage: "It happened also that the iron fled from the magnet, for it was seen to alternately fly from it and then seek it." One would think at first that the poet had seen the phenomena of magnetic attraction and repulsion, but the following shows that what he took for repulsion was no other than the attraction of iron from a distance through other bodies. "I have seen," he says, "at Samothrace, iron jump and filings dance in brass vases when a piece of lodestone was placed underneath, so that it seemed as if the iron was repelled from the stone." If Lucretius had turned the vase round, without withdrawing the magnet, to the opposite side, he would have seen to his surprise the iron particles remain suspended in spite of gravity, and he

λίθος. Aristotle called the magnet simply ἡ λίθος, that is to say, "*the* stone." The Romans called it *magnes*, from whence we derive our name magnetism, and also *calamitas* and *adamas*, the latter name giving rise to some confusion with the diamond. In the middle ages it assumed the name magnet, although the natural magnet was called *adamant:* this in turn gave rise to the modern French name *aimant*.

would have understood that it was always the phenomenon of attraction.

The lifting power of magnets was well known in ancient time. It was that particular property that would take their fancy and would lead them to exaggerate the effect; so in olden times, as in the middle ages, the most improbable stories were believed for some centuries. Let us quote some. After Pliny, Ptolemy Philadephus and his architect Dinochares had prepared for Queen Arsinoe the plan of a temple whose arch was to be built of lodestones in such a way that the iron statue of the new goddess should remain suspended by simple contact; Ansone gives the plan as carried out. St. Augustine says that pagan priests had spread magnets in the arch and under the floor of a temple to deceive people, and that the power of these magnets was calculated to hold suspended in the air an iron statue, which could neither rise nor fall, thus appearing to the devotees a perpetual miracle.

Many historians of ancient times and the middle ages record similar tales, amongst the most famous of which is the suspension of Mahomet's coffin from the ceiling of the mosque where he was buried.

Tales of another kind show how people were astonished by the curious property of magnetic attraction. "The celebrated astronomer and geographer Ptolemy says, from public report, the truth of which, by the way, he does not warrant, that the ships which go to the Manioles Isles would have been held there if they had not taken the precaution in building them to use bolts of wood instead of iron nails. Ptolemy asks if this was caused by the large mines of lodestone in the islands?" After Ptolemy has assigned the position of the Manioles between Taprobanus and the Golden Chersonese (Ceylon and Malacca), they without doubt are in the archipelago of Andaman or Nicobar. "According to Pliny there are near the Indus two mountains, one of which attracts iron and the other repels it; at a certain position a traveller who has nails of iron in his boots on one of the mountains cannot place his feet on the ground, whilst on the other his feet remain fixed to the ground."

We have seen that ancient people were quite ignorant of the process of communicating magnetism, and knew no other than artificial magnets. Yet Pliny had observed that iron after it had

been in contact with a magnet could attract iron, and could preserve it for some time after the contact had ceased. To sum up, what the learned men and philosophers of olden time and the middle ages knew about the magnet was limited to the attractive property of the natural magnet for iron; magnetic repulsion was not quite unknown, but they attributed it to a special kind of magnet by their absolute ignorance of that which explains magnetic polarity. In short, they had most exaggerated and most absurd ideas of the power of natural magnets. We shall soon see that the knowledge of one other important property was known in Europe towards the eleventh or twelfth century of our era; it is that a magnet supported in a horizontal plane, and free to swing on all sides, will always point in the same direction. The use of the compass, the construction of which depends upon this property, was not only of service in navigation and for the extension of geographical discoveries, but it also provided a means of studying more completely the properties of magnets. The introduction of this method of scientific experimental observation led later to many valuable results. From what remains of their writings one can see that the people of olden times were limited to pure observation; starting with some simple apparent fact, which most frequently they accepted on hearsay without confirmation, they argued with ingenuity, it is true, but very fruitlessly, about their causes. Hence the small progress which they made in physical science, and in particular the poverty of facts they had collected about magnets.

§ 3.—*Magnetic Polarity—Magnetic Attraction and Repulsion.*

We will now return to the subject of the magnetic polarity of artificial and of natural magnets. In natural magnets the points at which attraction takes place, otherwise called *poles*, are generally unsymmetrically placed, and depend entirely on the internal structure of the magnet, as well as on the irregularities of its surface. Therefore, for experimental demonstration, artificial magnets are always preferred. These are often flat bars or circular rods of steel. If proper care be taken whilst magnetising them, only two poles are formed, and these are very nearly at the ends. Sometimes magnets are made

of thin sheet steel cut into a very tapering lozenge. Such a magnet is called a magnetic *needle*. It is usually provided with a small cup-shaped bearing in the centre, so that it can turn easily when supported on a vertical point as a pivot. Agate centres are often used on account of their hardness. But for the finest work a sapphire cup working on an iridium point is employed. Let us take one of these needles and examine it. The first thing that we notice is that, after swinging several times from side to side, it always assumes a constant direction. This direction is found to vary with the locality. When we say that at the same place the needle always points in the same direction, we neglect to consider certain slight diurnal and other variations which take place; we only speak of the general position. If several needles are supported in this manner they will set themselves parallel one to the other, unless they are sufficiently close to one another to affect each other mutually (Fig. 6). The same experiment can be shown by suspending a bar magnet in a cardboard or

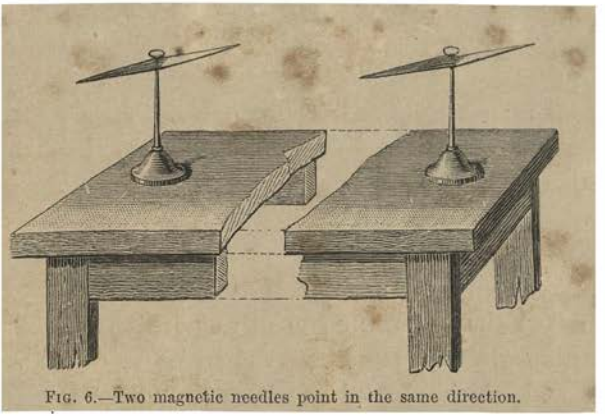

FIG. 6.—Two magnetic needles point in the same direction.

copper stirrup fastened to a torsionless thread or ribbon. A third way (Fig. 7) is to float a magnet on a piece of cork in a basin of water. The magnet, after moving from side to side, at last settles down in the same direction as in the other experiments.

This property is the one upon which the compass is constructed, and we shall see that it depends upon the magnetic action of the earth.

We can now for the first time make a distinction between the two poles of the magnet. When examining a magnet we find that not

only does the axis always keep the same direction, but that each end keeps to its proper direction; thus, if a needle be turned round through 180°, although its axis may be in the same direction, yet when released it will return to its original position. Thus, if the pole marked N, which usually points to the north, be turned to the

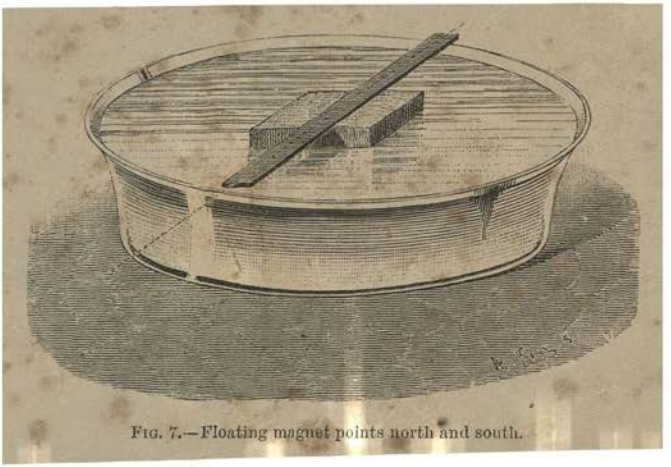

FIG. 7.—Floating magnet points north and south.

south, it will immediately endeavour to set itself right again. Thus showing that whatever the force consists in which draws the magnet into position, it is one which is capable of distinguishing between the poles.

Dr. Gilbert of Colchester was the first man who published any important work on this subject. He floated a magnet on water, having marked the poles so as to distinguish them. Near to this magnet he brought others and observed which of their poles showed attraction and which showed repulsion. Let us now repeat this experiment, but in a different way. Let us hang two bar magnets by threads attached at their centres of gravity. At first let them be so far apart that they have no effect on each other: they will lie parallel. Now let them be brought nearer: the two north poles will repel each other, and likewise the two south. But again let the north of one be brought near the south of the other; instead of repulsion we shall find attraction.

The principal points in this natural law can be proved without having previously determined the poles by their directive action. Take several bar magnets, and let one, M N, be used to test with.

If one pole M of this magnet be then presented to one pole of one of the others it will either repel or attract it. Suppose it repel it, then it will attract the other pole. By this test we can easily find the corresponding poles of the other magnets; for all those which are attracted are called *poles of similar name:* mark them with the letter A (attracted). All those repelled by the same pole M are also poles of similar name to one another: mark them with the letter R (repelled). If now the other pole N of the testing-magnet be

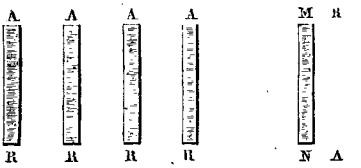

FIG 8.—Attraction and repulsion of poles of magnets.

presented to the other magnets it will be found to repel all those marked A, and to attract all those marked R. Now let us see what effect two of the poles marked with the same letter have upon each other. If two poles marked A are brought together they repel each other, if two marked R they repel each other. If, now, one pole A and one R be brought near to each other they will be found to attract each other. To sum up we can say,

The two poles of a magnet are of opposite kinds, for the action of one of the poles of one magnet on a pole of another magnet is a repulsion and on the other pole of that magnet an attraction. In other words, *like poles repel, unlike attract.*

§ 4.—*Magnetic Induction—Magnetisation by Induction.*

If a small piece of iron is placed in contact with a magnet near to one of its poles it becomes as part of the magnet with two poles and a neutral line; a second piece may be added to this, and becomes a magnet in its turn. The name of *magnetic induction,* or influence, is given to this series of phenomena of temporary magnetism. A series of pieces of soft iron can be thus suspended from the pole of a magnet, forming what is called a *magnetic chain.* As we have seen above, this was known in olden times.

Each element of the magnetic chain is in itself a complete magnet, having two poles and a neutral zone. At the junction between two consecutive elements there will be a pair of opposite poles. It is thus

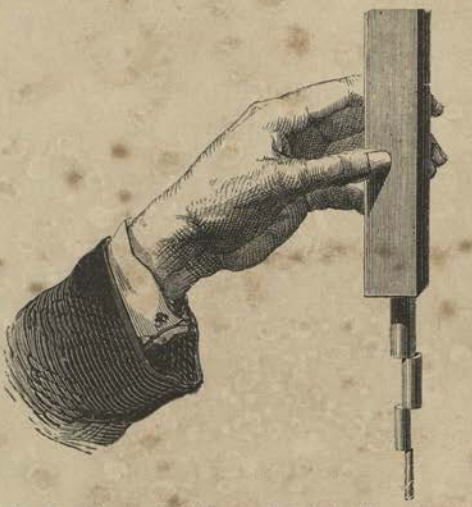

FIG. 9.—Magnetisation by influence at contact. Magnetic chain.

that the arrangement of the filings in Figs. 4 and 5 is explained. In these magnetic figures the filings arrange themselves in threads, each of which may be considered as a magnetic chain, the portions in contact with the magnet becoming also magnets, and attracting other portions to themselves.

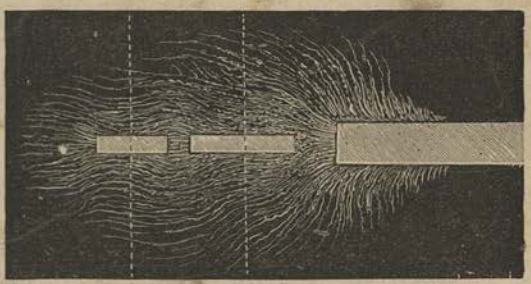

FIG. 10.—Filing-figures of bits of iron magnetised by influence.

When a magnetic chain is formed of rings, or pieces of iron, it is easy to show the arrangement of poles by sprinkling filings over it, and so obtaining the magnetic figures. Magnetic induction may

also take place at a distance (Figs. 11 and 12), but, however, to a less degree; depending upon the strength of the inducing magnet, and

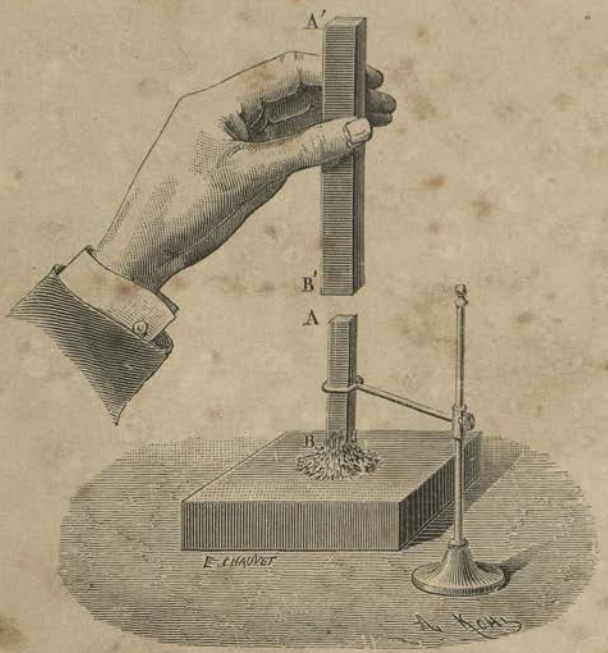

FIG. 11.—Magnetisation, by induction, at a distance.

the distance. In a magnetic chain hung from the pole of a magnet, the first element is more strongly magnetic than the rest, and the

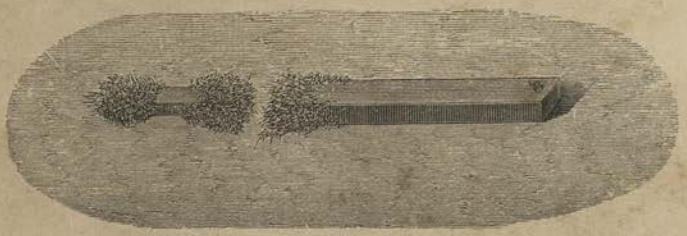

FIG. 12.—Magnetisation, by induction, at a distance.

strength of the successive pieces decreases until the final bit of iron is no longer able to support another.

We have said that magnetic induction is temporary. This is only so when the iron is very soft, as in this case magnetism is very easily induced and also very easily dispersed: whilst if the material be steel or hard iron, induction takes place with greater difficulty but is more permanent. Nickel and cobalt when combined even in very small quantities with carbon, sulphur, phosphorus, arsenic, or tin, behave more like steel and become permanently magnetised. We shall discuss this further in describing the methods of magnetisation.

Magnetism is intimately related to the internal structure of the magnetised body. When an iron bar is subjected to a strong magnetising force it becomes slightly longer. If the magnetisation is effected by means of an electric current circulating around the iron bar in a coil of wire, it is found that at the moment when the magnetising current is turned on or off a slight noise is heard—a sort of metallic click—in the bar, its molecules having been set in vibration as if they had received a blow from the invisible force. If a glass tube containing steel filings be subjected to a magnetising force it will be found that they range themselves in lines or threads from end to end, and the whole tube will then act as a magnet. But if this structure is disturbed by the shaking of the tube, then the magnetism also disappears. In general, changes of temperature, and mechanical vibrations, tend to destroy the magnetism of a magnet. It is detrimental to the magnetism of a permanent horseshoe magnet to slam its keeper suddenly upon its poles; the keeper ought to be placed on the magnet near its bend, and then drawn down gently to the poles.

CHAPTER II.

THE THEORY OF MAGNETISM.

§ 1.—*Polar Theory.*

AS soon as the properties of magnetic attraction and repulsion had been observed, people tried to put forth theories which should explain these effects and the existence of magnetic polarity.

Before passing on to the more recent theories, let us see how people in ancient times tried to explain what they knew concerning it.

The first was by Thales, who thought that the magnet was endowed with a soul capable of moving iron; then came Claudian, who considered that iron was simply food for the magnet. In the same way Lucretius considered the iron drawn into a vacuum, which was surrounded by the magnet, and extended out from it; there is nothing however in all this worth discussing.

Since the time of Gilbert, two or three theories worth mentioning have been propounded but have since been refuted. Æpinus proposed the existence of a fluid which would affect the molecules in magnets. Euler suggested that a subtle fluid was continually circling in magnets, in a given direction, always entering at one pole and leaving at the other; by the mutual action and reaction of vortices, this celebrated geometrician explained all the principal phenomena of magnetism.

Much more important was the theory propounded by Coulomb, which he adopted as the result of a large number of observations which without the theory would remain as isolated facts. This theory however teaches nothing as to the ultimate cause of the phenomena which without doubt have a common origin with electrical phenomena. If electricity be as we now believe purely a property of

the ether, the analogy between this and other physical forces will lead us to the conclusion that each is only a single case of a universal theory.

Coulomb explained all the magnetic phenomena by the supposition that in a magnet two opposite "fluids" existed.[1] These fluids, says he, are distinct from the solid matter of the magnet; this is proved by the fact that when a body is magnetised or demagnetised the other physical or chemical properties are not affected. Thus a piece of iron is of the same weight and chemical composition whether magnetised or not.

The magnetic fluids are then imponderable, they exist in equal quantities in all magnetic bodies, where they neutralise each other and only become apparent when a magnet is brought near to the body. To explain the general properties of magnets it is assumed that the two fluids attract each other, but different portions of the same fluid repel each other. One of these is called the North and the other the South fluid.

When a bar of steel is magnetised the two fluids are separated and forced into the two poles of the magnet; thus it is weakest in the middle. When a piece of soft iron is brought near the pole of a magnet, the two fluids are separated towards each end, those of opposite kinds being attracted whilst those of like kind are repelled. To illustrate this ingenious theory suppose a piece of soft iron be held by the north-pole of a magnet, a south-pole will be induced nearest at the point of contact, and a north-pole at the other end. Now supposing another magnet of equal strength be brought near the first magnet but with the poles reversed; now this will induce just the reverse magnetism in the soft iron and the result will be that the soft iron is not magnetised at all and therefore drops off (Fig. 13). This may be again illustrated by taking a magnet made of steel-spring; if this be so bent that the two ends are brought together it will be seen to have no effect on a suspended needle (Fig. 14), thus also proving that the two poles of the magnet are equal in intensity.

[1] [It cannot be too early pointed out that this theory of "two fluids" is a wholly arbitrary hypothesis, and that the fluids have no real existence. They are only a convenient mathematical fiction. Sir W. Thomson has proposed to substitute the words "imaginary magnetic matter;" whilst Sir G. Airy uses instead the terms "blue magnetism" and "red magnetism," for convenience of reference. No one now believes in the existence of the alleged magnetic "fluids."]—ED.

The fluid theory is based on the existence of the two adverse properties in the poles of magnets; thence comes the query, how are these distributed in magnetic substances?

As magnets consist each of two poles and a neutral portion between them, there may be many ways in which they may be arranged in the mass.

Before the theory of Coulomb, people considered that the two fluids were bound up each in its own half of the magnet, and each driven by forces at the end of the magnet: so that, if it were possible

FIG. 13.—Neutralising action of two poles of opposite kinds.

to break the bar suddenly, each part would have only one kind of fluid in it. This, however, is not in accordance with Gilbert's discoveries, who, when he broke a magnet in two, found that each part was in itself a perfect magnet containing two equal poles. This subdivision may be continued further. Let us take a magnetised knitting-needle and break it into several pieces, each piece will be a perfect magnet, and its poles will be nearly of the same strength as those of the whole magnet.

Still further, if the pieces are examined as they are broken off, it will be found that each breakage forms both a north and a south

pole. And when all the pieces are arranged in order, all the north poles will be in one direction, and all the south poles in the other.

This being so, we are driven to the same conclusion as Coulomb, that each particle is in itself a magnet, and must modify the two-fluid notion so far as to suppose that each separate particle has equal portions of both fluids in it. In fact each particle possesses *polarity*.

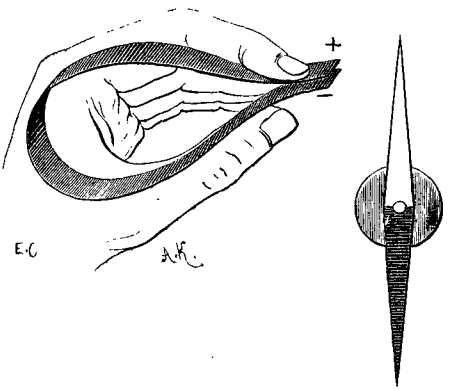

FIG. 14.—Neutralising action of two equal poles.

It is by supposing that the particles are thus individually magnetised that we can explain the difference between magnets and magnetic substances.[1] In the case of magnets we have observed that even the particles are magnets: then we have to suppose the existence of some internal force, which prevents the two fluids from running

FIG. 15.—Distribution of poles in the fragments of a broken bar-magnet.

together from one particle to another; this force we call the *coercitive force*, or now more commonly the *retentivity*, because it is that which tends to *retain* the magnetic condition. Magnetic substances, that is

[1 If we are driven then by the facts of the case to consider every particle of a magnet as being individually magnetised, there is no longer any need for the impossible and illogical hypothesis of two mutually destructive fluids.]—ED.

to say those substances which, though magnetic, are not permanent magnets, have not this retentivity; they are only magnetic whilst acted upon by magnetic induction, and as soon as the induction ceases the substance is no longer a magnet.

The same cause which makes the particles retain their magnetism also operates in causing the particles to resist magnetisation. Steel is harder than iron to magnetise: but it retains more magnetism. The fluid theory gives no explanation why a supposed coercitive force should act in this double fashion. The theory that a magnet is such by virtue of the magnetism in its particles is confirmed by many proofs.

Let Fig. 16 be a series of particles 1, 2, 3, 4, 5, 6, 7, so arranged that each is attracting each; that is to say—that all the north-poles point one way and all the south the other. Let us examine the action of each particle on the one which precedes it, and the one which follows it.

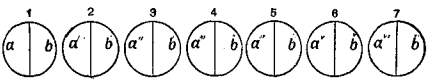

FIG. 16.—Mutual actions of magnetic elements.

The pole a', particle 2, repels a, particle 1, and attracts b, but the attraction is through a less distance than the repulsion, and is therefore stronger; again, b', particle 2, repels b, attracting a, but these actions although contrary to a', are at a greater distance, and therefore of less intensity. Similarly 3 acts on 1 in the same way as 2, but with a still less extent. It is clear that one would find the same kind of result if one was to analyse the effect of each particle on the hundred that succeed it: but the forces would be much less for particles that were remote.

It only remains to compare the individual members of a single row or series of particles, in order to deduce from their mutual influence the total effect.

Let us suppose that the series 1 to 7 extends from end to end of a bar-magnet. The first particle in the row is acted upon by the other six, with forces f_1, f_2, f_3, f_4, f_5, f_6, decreasing with the distance. Let F be the sum of these forces, $F=f_1 + f_2 + f_3 + f_4 + f_5 + f_6$. In particle 2 let F′ be the sum of the forces $F' = 2 f_1$

$+ f_2 + f_3 + f_4 + f_5$. In particle 3 the sum $F'' = 2f_1 + 2f_2 + f + f_4$. In particle 4, sum $F''' = 2f_1 + 2f_2 + 2f_3$. Starting from the other end we get a similar series of results for the particles counted from that end, and a simple comparison will show at once that the greatest force is exerted between the middle particles.

From this it would at first appear that the centre particle should be the most strongly magnetised. This apparently contradicts the existence of the neutral zone at the middle of every magnet. The paradox is, however, only apparent. Let us examine

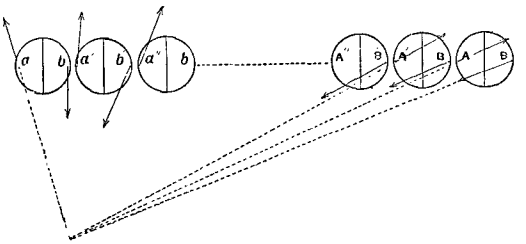

FIG. 17.—Action of a row of magnetic particles on an external point.

the action of such a series of particles on an external magnetic pole a, having polarity like a. Then all the a poles of the particles are repelled and all the b poles attracted. The pole a at the end of the series is repelled by a, but the pole b besides being attracted by a is attracted by a'. But, as we have seen above, the mutual action between the particles increases towards the centre, therefore the action on an external pole will decrease towards the centre and will reach a maximum at some point near the end of the bar. In the same way the other half of the bar can be treated, thus showing that the positions of greatest intensity on external objects are points very near to the two ends.

We will next describe the action of the earth on a freely-suspended magnet.

§ 2.—*The Action of the Earth, considered as a great Magnet, on a Magnetic Needle.*

We have so far seen that the hypothesis of a double polarity can explain all the magnetic phenomena of magnets upon magnets.

How does this hold with respect to the action of the earth on magnets?

We have already seen that a magnetic needle when freely suspended tends to set itself in a constant direction. What is there to cause it always to set itself in this direction?

Let us take as our magnetic needle a long lozenge-shaped piece of magnetised steel; each of the sharp points will then be a pole and

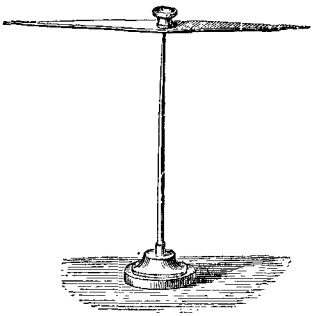

FIG. 18.—Magnetic needle.

there will be a neutral zone between them. If a magnet of this kind be suspended by a torsionless thread or supported on a sharp pivot (Fig. 18) so as to turn freely in all directions, it will invariably come to rest in a constant direction. It is from this property that the use of the compass originates. The compass, however, does not point geographically north and south, but at a slight angle with the meridian, which angle is called "the angle of declination" or briefly "the declination." In nautical language this angle is called "the variation." In the chapter on terrestrial magnetism, we shall show how the declination varies over the earth; how in some places the compass points true north, in others slightly to the east, and again in others slightly to the west (Fig. 19). At the present time the compass has a westerly declination at London of about 18°. That is to

say, instead of pointing true north, the compass points nearly to NNW.

Thus far we have seen that the compass points in a fixed direction: supposing it to be turned round through 180° it still is pointing in the same line; but it will not remain so, for as soon as it is set

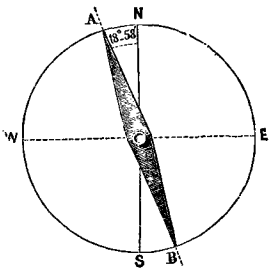

FIG. 19.—Magnetic declination of the compass.

free it swings back and finally comes to rest with the same pole pointing in the original direction, thus showing the action of the earth on the needle to be like that of one magnet on another.

Let us now take another needle and instead of supporting it about a vertical axis, let us support it about a horizontal one, so that it can move in a vertical plane (Fig. 20). Now if it be so turned that the

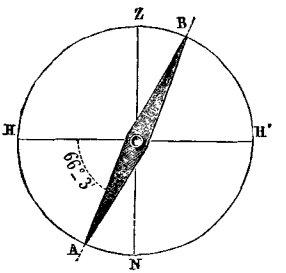

FIG. 20.—Dip of the magnetic needle, as it was at Paris in 1864.

needle be in the magnetic meridian, although the needle be perfectly balanced, the pole pointing to the north will be found to dip to a considerable angle. This angle is called "the angle of inclination" or more commonly "the dip."

The dip of the needle varies in different places; in one zone round

the earth there is no dip, the needle remaining horizontal, whilst at one point on either side of this zone the needle stands vertical.

For convenience in illustrating these properties a piece of apparatus (Fig. 21) may be used which consists of a needle suspended about a horizontal axis in a stirrup of wire; this stirrup being suspended by a torsionless thread. For the purpose of accurate measurements far more delicate apparatus has been devised which we shall describe in its proper place.

Having carefully observed how the magnetic needle behaves, we must next inquire into the causes. At first these causes were

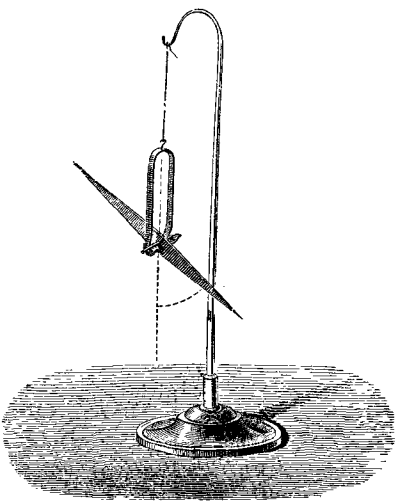

FIG. 21.—Magnetic needle suspended, so as to show both declination and dip.

sought for outside the earth: it is to Gilbert that we have to give the honour of first showing that it is the earth itself that acts as a great magnet. The earth is in fact a lodestone whose magnetic poles are situated one in the Arctic and the other in the Antarctic regions: its neutral zone being that region where the compass needle has no dip.

This can be illustrated in the following way.

Take a long bar-magnet and also a compass needle mounted as described above so that it can move in every plane. If this be placed over the bar in a central position it will place itself so that the

N. pole of the needle is pointing to the south-pole of the magnet, but will remain in a horizontal position. If the needle be then moved along the big magnet towards the end it is found that the needle will

FIG. 22.—Directive action of a bar-magnet on a compass needle.

begin to dip towards that end, until, when it has reached a point near the end, it stands in a vertical position. This series of positions (Fig.

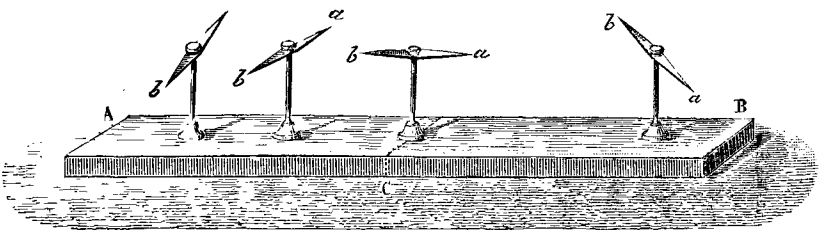

FIG. 23.—Action of a bar-magnet on a magnetic needle.

24) corresponds to those observed on moving a compass needle from the magnetic equator, or zone of no dip, to one of the magnetic poles,

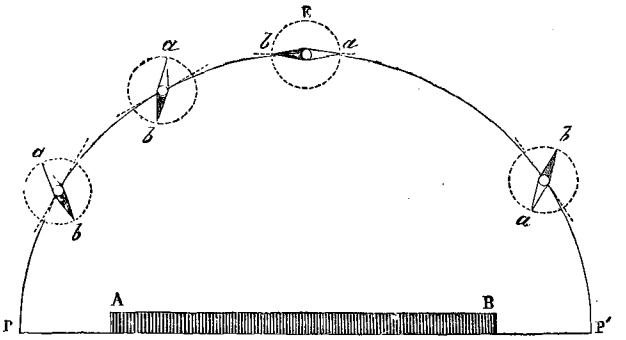

FIG. 24.—Resemblance of action of bar-magnet to that of the globe.

showing that in this as well as in other respects the earth behaves as a great magnet. Here is another point which bears out the same theory; just as a magnet is capable of inducing magnetism in soft

iron, so it is found that if rods of iron are placed in a similar direction to that which a dipping needle assumes, they will be found to become magnets.

The action of the earth on magnets is purely directive: it cannot give them any movement of translation. This is easily shown by placing a magnet on a cork in a basin of water; the directive force causes the magnet to assume at once its proper north and south direction; but it is not drawn along either one way or another in the magnetic meridian.

If the terrestrial magnetic force were a single force, it could have no unbalanced horizontal component, neither could it have a vertical component, for this then would act as gravity does, and would cause the weight to vary; but this is not so, the weight of a body is not affected by being magnetised. For the proof of this we are also

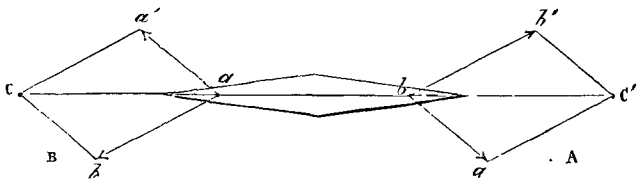

FIG. 25.—Action of terrestrial magnetic forces on a magnetised needle, giving rise to a "couple."

indebted to Gilbert. The directive force of the earth can then only consist of a pair of equal and opposite forces such as constitute in the language of engineers a "couple."

The supposition that the earth is a big magnet with its poles in its polar regions is then amply justified. And, in fact, a needle free to move is affected by two terrestrial forces, one tending to pull its N. pole northward, and one tending to pull its S. pole southward, and as the needle is infinitely small compared with the magnet these forces are equal and opposite. They tend to twist the needle about its point of suspension and to bring it into line with themselves where it will be in equilibrium (Fig. 25). The intensity and direction of the directive couple varies with the locality, in consequence of local irregularities in the distribution of iron and rocks containing iron, in the mass of the earth.

§ 3.—*Laws of Magnetic Attraction and Repulsion.*

If we observe the action of one magnet on another the first thing that strikes us is that if two similar poles are brought near together, they repel each other; but if two dissimilar poles are brought together they attract each other. This then is the first law: but if we search a little further we shall find that by varying the distance between the two magnets the force varies: but not in proportion to the distance. Coulomb worked this out experimentally and gave us the following law:—

"*Magnetic attractions and repulsions vary inversely as the square of the distance.*"

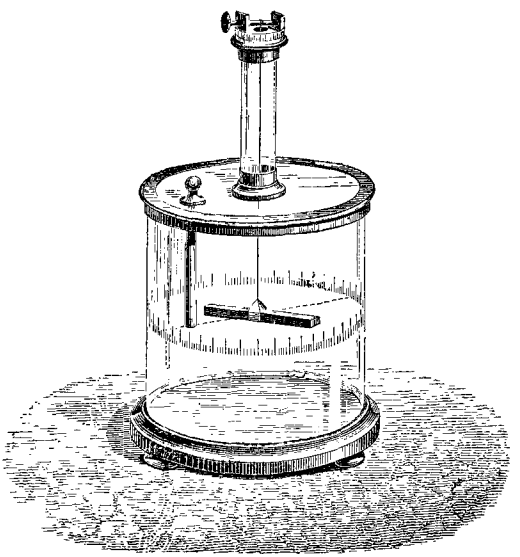

FIG. 26.—Coulomb's magnetic torsion balance.

To verify this formula Coulomb used the apparatus known as the *torsion balance,* shown in Fig. 26.

The torsion balance consists of a glass case either square or round carrying on the outside a divided scale which is used to measure the amount of deflexion of the magnet. A long bar-magnet is suspended in the centre so that the magnet is in the same plane as the scale.

The thread supporting the magnet is carried up through a tall tube and is attached at the top to a milled head which carries a pointer over a divided circle, by which means the angle of torsion given to the thread is measured.

As a preliminary experiment it was necessary to determine the position of rest of the torsion thread; this was done by placing in the stirrup a bar of copper, the same weight as the magnet; having observed the pointer of the torsion head, and read off the angle of the bar of copper, he then replaced this by the magnet he intended to use for his experiment. The magnet then twisted the thread, and set itself in the magnetic meridian, the torsion on the thread was then released by bringing the pointer into the same position as the magnet. In this position there was no torsion. This having been done, the torsion-head was moved round so as to twist the magnet through a small angle out of the magnetic meridian. Suppose this angular displacement to be 2° and that it required a torsion of 72° at the torsion-head, to bring the magnet from the meridian to this position of 2°. Then the difference, namely 70°, is the torsion on the thread which balances the directive force exercised by the earth on the needle in this position. In order to obtain an angular displacement of double the amount, namely 4°, the torsion-head would have had to be turned through 144°, giving a total torsion of 140°. The actual amount of torsion on the thread in the two cases was 70 and 140, which are in the ratio of 1 to 2; but the force in the second case was double that of the first, and as the angle of torsion is proportional to the force, this showed that in this case a torsion of 35° was required for every degree that the magnet is moved from the meridian. Had a heavier or a more powerful bar-magnet been used, the actual number of torsion-degrees requisite to draw the bar 1° out of its position of equilibrium would naturally have been different from the 35° of this particular case: but the proportionality would still hold good for small angles.

The experiment was then conducted in the following way. It was first necessary to arrange the apparatus so that when the magnet was in the meridian, there was no torsion on the thread; secondly the hole in the cover had to be brought into the same plane as the magnet. Through this hole was then lowered a magnet so as to bring similar poles together, and therefore cause repulsion. The bar-magnet was

found to be repelled to an angle of 24°. To bring this deflexion down to 17°, it was found necessary to turn the torsion-head through three complete turns or 1080°; and, to reduce the angle still further to 12 it was found necessary to give five more complete turns to the torsion-head, or 8 times 360° in all. In each position the repulsion between the magnets had to overcome two forces, the directive force of the earth, and the torsion of the thread. The first force is obtained by multiplying the angle of deviation from the meridian by 35, and adding the angle to this result. The force of repulsion in the three positions was:

1st position	$24° \times 35 + 24°$	$= 864°$
2nd ,,	$17° \times 35 + 17° + 1080°$	$= 1692°$
3rd ,,	$12° \times 35 + 12° + 2880°$	$= 3312°$

These three numbers are approximately in the inverse ratio of the squares of 24, 17, and 12; in other words the forces are in the inverse ratio of the squares of the angles between the magnets. The law may be worked out in the same way for magnetic attraction, only in that case the torsion has to be given in the reverse way, and the equilibrium is always unstable.

Coulomb also verified this law in another way; by *the method of oscillations.* If a freely-suspended needle is drawn aside out of its position of equilibrium, that is to say out of the plane of the magnetic meridian, and then left to itself, it oscillates like a pendulum. Let the number of oscillations executed per minute be counted. If now we place vertically in the magnetic meridian a magnet, one pole of which is near to the pole of the needle, the needle will be more strongly attracted, and will vibrate more rapidly to and fro. If the influencing magnet be so long that its other pole is so remote from the needle as not to sensibly affect it, we may confine our attention to the oscillations executed under the joint influence of the earth's attraction, and the attraction of the neighbouring pole. The rule is that the intensity of the magnetic forces is in the ratio of the squares of the numbers of oscillations of the needle.

Observations are then taken at double and triple the distance, and from these results we shall obtain the same law.

§ 4.—*Distribution of Magnetism in Magnets.*

The two methods by means of which Coulomb verified the foregoing laws, enabled him to study the distribution of magnetism in magnets. That is to say, how the magnetism at the surface varies along the magnet between one end and the other. For this purpose Coulomb took a small needle and placed it near to a large bar-magnet and observed the number of oscillations. At the centre of the bar-magnet of course the oscillations were simply those due to terrestrial magnetism. Then he took a series of points at different distances

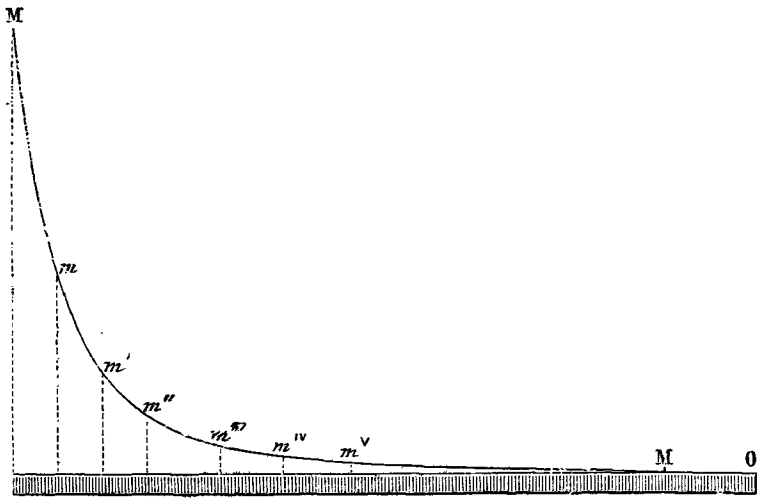

FIG. 27.—Curve showing relative strength of magnetism at different points along a bar-magnet.

along the magnet, and observed the oscillations at these points; at first the oscillations increased very gradually, but as he approached the pole, the increase grew more rapid, and attained a maximum at the end. On plotting out his observations he found that he was able to express the variation of intensity in the form of a curve (Fig. 27), such as $M\,m\,M'$, the ordinates of which correspond to the squares of the oscillations (less the square of the oscillations due to the earth's magnetism alone), the maximum ordinate being at the end of the bar

at A. For any whole magnet the curve will have two equal branches, one drawn above, with positive values, representing the forces due to the magnetism of one polarity; the other drawn below the horizontal line, with negative values, representing the forces due to the polarity of the other half.

The positions of the "poles" will be the points of application of the resultants of the magnetic forces for each half of the bar. Coulomb found that the curve remained the same for magnets of various lengths, provided they were not more than 20 centimetres long (8 inches); but the neutral region where the surface magnetism is imperceptible, and which forms the middle of the bar between the two curves, is longer or shorter in different cases; and when the magnet itself exceeds 20 centimetres is always of considerable length. He observed that in magnets exceeding 20 centimetres

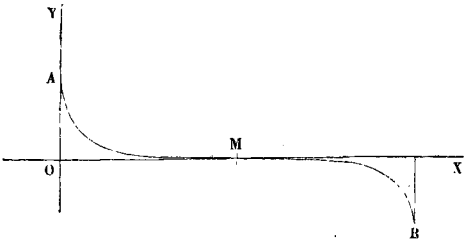

FIG. 28.—Complete curve of distribution of magnetism along a bar-magnet.

the poles are always at the same distance from the ends, and he found that distance to be about 4 centimetres.[1] For very short magnets the curves of distribution are reduced to straight lines inclined to the axis and cutting its middle point. And in this case the poles are at about $\frac{1}{6}$ of the length of the bar from either end.

In all his researches Coulomb used cylindrical or prismatic magnets magnetised with regularity. He also found that if "consequent points" were formed, the law of distribution was not the same. In lozenge-shaped compass-needles the poles are nearer to the middle, the shorter the needle in proportion to its breadth.

The distribution of magnetism in magnets has more recently been

[1] [This is not always so: the distance of the pole from the actual end of the magnet depends on the thickness of the magnet and on the quality of the steel: also partly on the method of magnetisation adopted.]—ED.

made by M. Jamin the subject of important researches: we will summarise his principal results.

In order to measure the power of a magnet M. Jamin employs a method which "consists of placing, on the point that we wish to study, a small contact-piece of soft iron and of measuring, by means of a graduated spring that is gradually extended, the force requisite to detach the iron. But this force depends upon the size and shape of the piece, and it is then necessary to fix the size of this contact-piece if it is desired to reduce all the observations to a convenient unit that can be easily reproduced." M. Jamin takes as a unit a thread of iron wire one square millimetre in cross-section and of an indefinite length. In practice he used a small ball of soft iron suspended from the arm of a balance, and which is put in contact with the surface of the magnet. To the other arm of the balance the spring to be stretched is attached. The spring is stretched by winding a thread attached to it round a drum which carries a micrometer head, until sufficient pull is obtained to detach the iron bead. The force requisite to detach the soft iron bead is measured at each point on the magnet. This process is known as that of the *proof ball.* From this a curve can be drawn of the distribution of magnetism in a magnet.[1]

In magnets formed of an increasing number of layers, M. Jamin has observed that the curves rise in proportion to the increase in the number of layers, but their two parts approach nearer and nearer to the middle of the magnet, until at a certain moment they meet at the middle.[2]

"At this point," he says, "the bundle has reached its maximum power, the largest number of layers produces now no change in its strength at any point; if it be now taken to pieces so as to study each of its component layers separately, it will be found that the more of them there are, the more of their former magnetisation will they have lost. As a result, the increase in the number of layers beyond the limiting number is nothing more than a useless waste of steel." M. Jamin has called a magnet thus built up a

[1] The force is proportional to the square of the magnetic strength, which can easily be calculated from the observed forces.

[2] Coulomb and Nobili had already studied the magnetic condition of bundles of superposed layers, and observed that they reacted amongst themselves until their magnetic force is far from increasing with the number of layers.

"normal" magnet. It possesses the remarkable property that the curve of magnetic intensity is reduced to a straight line, and that the poles are at one-third of the half-length of the magnet. This is the case observed by Coulomb where the magnets were 4·5 millimetres in diameter and were only 135 to 162 millimetres long.

The number of layers in the normal magnet increases with the length; it is 3 or 4 for 100 millimetres, 6 or 8 for 200 millimetres, and 9 to 14 for 300 millimetres. It is difficult to be more accurate, as the force which at first increases rapidly with the number of layers only very slowly reaches its maximum.

What is the internal distribution of magnetic force in a prismatic bar-magnet? According to Coulomb's experiments one would infer that the force decreases from the exterior to the interior. M. Jamin has proved that the magnetisation penetrates to a finite depth in steel; he has moreover found the limit of that depth and the law of the decrease of intensity from the surface to the limit. He considers a bar-magnet composed of threads or single chains of small magnets which are arranged in a series with their opposite poles in contact. These threads are inactive throughout their length, except at each end where there is a free pole. In bar-magnets they are parallel to the axis until near the ends where they spread out and diverge. Experiments made on a series of layers of steel of increasing thickness have shown that the single threads penetrate to a depth of 3 or 4 millimetres; he then concludes that, in a thick bar of steel there is no magnetisation at the centre; that the single threads only begin to appear at a distance of 3 or 4 millimetres from the surface, but they increase and collect more and more at the surface.

From this one concludes that, after a certain magnetisation, the number of magnetic fibres which constitute the magnet is proportional to the depth that the magnetism has penetrated, and to the perimeter of the mean section. M. Jamin says: "If the perimeter increases or decreases this number increases or decreases proportionally; because the quantity of magnetism in the magnet is exclusively governed by the mean section and does not at all depend upon the longitudinal shape or length of the steel. One condition, however; it is that the fibres find towards the ends of the polar surfaces sufficient room to spread. If the steel is very long the two principal poles are at the two ends, and the two curves of magnetic intensity

are at some distance from each other. If the length decreases the curves approach without altering and without any change in the quantity of magnetism. If the steel continues to decrease the curves finally meet. From this point they overlap, forming two opposing curves and their area which expresses the quantity of magnetism decreases. I explain this by saying that in the first case the magnetic fibres have more room than they need to expand in. When the curves touch they have just the required amount of room, and inversely the number of single fibre poles that the polar surfaces can receive is just equal to that that can be contained in the mean section. In that case the magnet is saturated and is perfect. In the preceding case the surface is not saturated. Now let us still decrease its length, the shortest fibres disappear because their two poles become united, and the quantity of magnetism decreases because of want of space for the distribution of the elementary poles. In the first case the mean section was too small, in the last it was too large, and in the intermediate case it was the correct polar surface for the surface of expansion.

"Generally the bar is only superficially magnetised; if it was equally magnetised throughout its mass to its axis, the number of magnetic fibres would be proportional to its mean section. This may be attempted by dividing the steel into thin layers, magnetising them separately and then superposing them; the number of fibres then increases proportionately to the number of layers, and as the surface does not change, they increase with the thickness until the magnet reaches saturation, the intensity curves meeting in the middle, and the magnet is saturated in all directions, since in the first place the mean section is magnetised to the core, and that, secondly, the intensity curves cover the whole exterior surface. Thus we can see why compound magnets are stronger than magnets made of one piece of the same total thickness." These opinions are founded on a large number of experiments, and if we have gone into them at some length, it is not only because they are interesting for the theory of magnetism, but also because they have led their author to lay down some new rules for the construction of pole-pieces and armatures. We shall refer to them in the following chapter.

The two-fluid theory, of which we have just given in this chapter an elementary outline, was propounded before the discovery

of the facts which have permanently connected the phenomena of magnetism with electric currents. It is sufficient to give an account of the principal properties of magnets, and their mutual attraction and repulsion, of their action on simple magnetic substances, such as soft iron; they will make more plain what occurs when one employs the processes of artificial magnetisation, which will be described in the following chapter; and, in a word, they are sufficient to connect all the general facts in showing that they all proceed from one common principle.

But it is well to insist on one point, namely that the theory of two fluids, of magnetic elements, of coercitive force, is not a reality but is only a temporary hypothesis, which will need to be modified and completed to explain the mutual actions of electric currents and magnets. When in the chapters devoted to electro-magnetism we shall describe these effects, it will be time to say what new hypotheses they have suggested. In the meantime the reader should refer to the concluding remarks on page 18 respecting the relation of magnetism to structure. The newer hypotheses, whenever we may consider them, must be capable of accounting for these facts. In this chapter we have shown that many of the phenomena are perfectly accounted for, and indeed can only be accounted for, on the supposition that all the particles of a magnetic body possess *poles*. Granted that the particles have poles, then all that the act of magnetisation accomplishes is to arrange the particles with their poles in certain directions. But we have yet to frame a theory to account for the particles having poles.

CHAPTER III.

METHODS OF MAGNETISATION.

§ 1.—*Magnetisation by Natural or Artificial Magnets.*

MAGNETIC substances when placed near to or in contact with magnets become magnets by induction, as we have described above. Our object in this chapter is to inquire by what methods we can render permanent these effects, which only exist, under ordinary circumstances, during contact with or in the presence of a magnet.

The old two-fluid theory supposed the action of a special force, the so-called coercitive force, by which the two magnetic fluids were held apart when once separated, and by which also their separation when combined was hindered. According to the more modern views magnetism is an inherent property of the particles, and its development is due to the particles turning round and pointing along, inside the substance of the steel, in a common direction; the operation of turning the particles thus being effected by the methods which we call "magnetising." The coercitive force, in this view, is the force required to twist the particles round, or the force which keeps them so when once they have been turned. But how is this coercitive force developed?

Of all magnetic substances, hard tempered steel has the greatest coercitive force, but if it be re-heated to redness, it at once loses it. Soft iron has practically no coercitive force, but if it be subjected to any stress such as percussion, torsion, flexure, or the like, then such force is developed in it. From the foregoing remarks it seems probable that coercitive force depends more upon molecular structure than upon chemical constitution. It is owing to this retentive property that steel is chosen for making magnets.

When a bar of this metal is placed under the action of a magnet, the magnetism developed in it remains indefinitely; this permanent magnetism is also proportional to its coercitive force.

Magnetisation is best produced by special methods which we will now describe.

If a bar of steel which is to be magnetised be placed with one end against the pole of a powerful magnet the piece of steel will become a magnet. Two poles will be developed, one at each end, and it will have at the point of contact a pole of opposite kind to that pole of the magnet which it touches. This is called the method of *simple contact* (Fig. 29), and is based upon simple magnetic induction.

FIG. 29.—Magnetisation by simple contact.

The method of "single touch" (Fig. 30) consists in drawing the pole of a magnet along a piece of steel several times in the same direction, when the steel becomes magnetised with a like pole to the

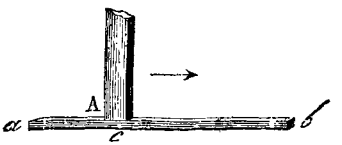

FIG. 30.—Method of single touch.

magnetising pole at the end at which the magnet is at first applied; and with an opposite pole at the end at which the magnet leaves it.

What occurs during this operation, and how can we express the result?

At a given point of the stroke, the north-pole A attracts all the little south-poles and repels all the little north-poles of the particles that are close to it, and therefore tends to make them turn round and point with their south-poles toward the retreating north-pole A. Opposite the point of contact there is a "consequent point," magnetised oppositely to A; and on each side of it the molecules are being magnetised opposite ways. But as soon as the magnet arrives

at the end of its path, the distribution is the same throughout: the bar is magnetised so that at the left there is a pole a similar to A, several similar strokes increase the same effect. The magnetisation then becomes stronger and stronger until it reaches a finite limit.

A bar is said to be magnetised to saturation when no more magnetism can be retained by it; under some circumstances this limit may be temporarily overpassed, but when this is so it is found that the magnetisation afterwards decreases until it is just under the limit.

The method of single touch is very good for short magnets, but with long ones it is often irregular and is apt to produce "consequent

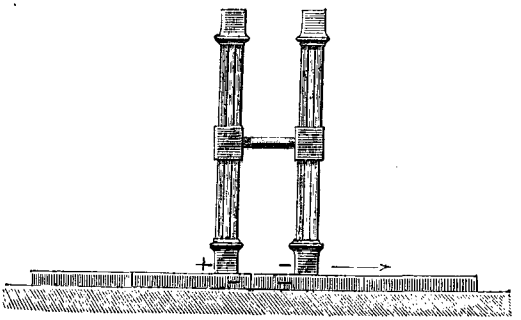

FIG. 31.—Method of double touch. Mitchell's process.

points." This method alone was known before the middle of the last century, but about that time Knight, Mitchell, Duhamel, and Aepinus each used the method of *double touch*, in which two magnets were used at the same time.

Mitchell's method consisted of using two magnets fixed parallel to one another, separated by a non-magnetic substance, such as wood, and with their poles opposed to each other. These were then moved along over the bar of steel to be magnetised (Fig. 31). When several bars of steel were laid in a row to be magnetised it was found that the intermediate bars were magnetised more strongly than the others.

Duhamel's method, or the method of "*divided touch*," consisted in placing the bar MN to be magnetised with its ends resting on the

opposite poles of two [1] powerful magnets A′ B′. The two magnets A B, were then placed on the middle of the bar inclined at an angle of from 25° to 30°, with poles corresponding to those of the magnets upon which the bar rested. The magnets were then separated, and drawn each to its end of the magnet, without altering its inclination; then raised from the magnet and placed at the centre of the bar, this operation was repeated until the magnet had reached the required strength. Duhamel's method gives perfectly regular magnetisation and is used for compass needles and strips less than five millimetres thick.

Aepinus' method (Fig. 32) differs from Duhamel's, by having the moveable magnets attached together as in Mitchell's method, but is

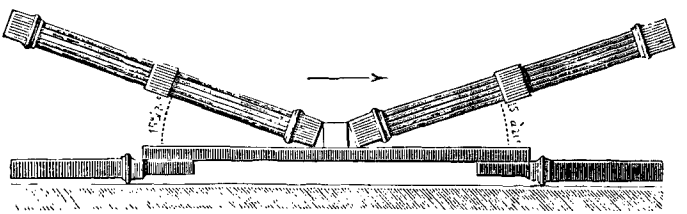

FIG. 32.—Magnetisation by the process of Aepinus.

similar to it in having the magnets inclined to the surface of the bar to be magnetised. Experiment has shown that the best effect is produced when the angle of inclination is from 15° to 20°. Aepinus' method is more powerful than the foregoing ones, but produces an irregular magnetism with secondary or consequent poles at other points than at the ends of the bar.

This was the state of knowledge about magnetisation before the discovery of electric currents, but now we are able by passing a current through a coil of copper wire round a bar of steel to produce a more powerful magnet, and one that is more regularly magnetised. We cannot, however, enter into this fully until we have described the main points in electro-magnetism.

[1] Duhamel at first placed two bars of soft iron under the bar to be magnetised instead of two magnets.

§ 2.—*Construction of Magnets—Compound Magnets—Pole-pieces.*

The power of a magnet is not in proportion to its size or its weight; the smallest having often the greatest relative force. But if several bar-magnets be placed together with their similar poles in the same direction, then a magnet is produced which is almost as strong as the sum of the strengths of the individual magnets. This arrangement is called a *compound magnet* or magnetic battery. The first idea is due to Knight; Coulomb and Scoresby used and studied this construction, but the final investigation of the best conditions is due to the late M. Jamin.

Coulomb showed that in a compound magnet the layers reacted one upon the other, resulting in an alteration of the magnetic condition of the inner ones, and that the total force was not equal to the sum of the individual forces of the component magnets. Nobili got over this difficulty by making the component strips of varying lengths, the longest being in the middle and decreasing in length outwards. Scoresby found it best to separate each strip from the others, only uniting them at the ends; Fig. 33 shows a magnet arranged in this form. There is in the possession of the Royal Society of London a magnet built by Knight which will lift 50 kilogrammes; it consists of 450 strips and is 40 centimetres long. This magnet formerly was much stronger; but it seems to have suffered from the heat to which it was accidentally exposed in a fire.

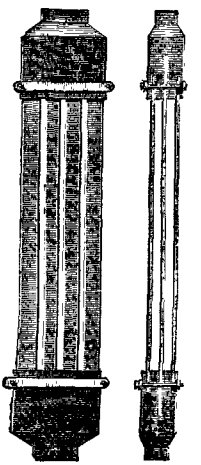

FIG. 33.—Compound magnet formed of twelve bar-magnets.

On examining Fig. 33 it is noticed that the component strips are joined at each end by pieces of soft iron called *pole-pieces;* the action of these pole-pieces is to combine the action of the component strips, thus producing one powerful pole; but at the same time they have according to some authorities an accumulating action to increase the strength of the magnet beyond the sum of the component strengths. What they do in reality is to concentrate the magnetism of the scattered

poles into one strong polar region. Knight was the first to use pole-pieces, or, as they were then called, *armatures*, that is to say,

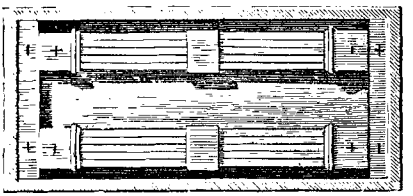

FIG. 34.—Pair of compound bar-magnets with armatures or keepers.

soft pieces of iron placed across the ends of magnets to concentrate their power. Knight also placed two of his magnets in a box with

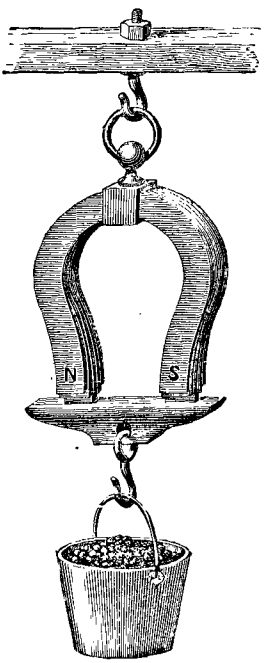

FIG. 35.—Horseshoe compound magnet, with its armature carrying a load.

their poles reversed and placed a strip of soft iron across the ends of them. These strips have opposite poles induced in them, the

action of which is to preserve the strength of the magnet when it is not being used.

Compound magnets are often used of a form bent round so that their poles can be joined by one armature. These are called *horse-shoe magnets* (Fig. 35). Sometimes two compound bar-magnets are placed parallel to one another with their poles reversed (Fig. 36) and are then united across the top by a yoke of soft iron; the whole being bound together with copper strips. Another piece of soft iron with a hook attached is used as the armature as with a horseshoe magnet.

The armature in these magnets serves to measure the lifting power. Beneath the weight is hung a light scale-pan, and so one

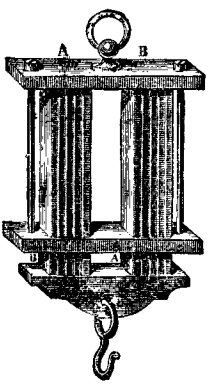

FIG. 36.—Magnet formed of two parallel compound magnets.

can verify that which was stated previously about the effect of armatures in increasing the power of a magnet. Day by day we may add a small additional weight to that which the magnet would carry on the previous day; but should the armature once be detached from the magnet, then it will be found that the magnet no longer possesses this excess of power. If it was previously saturated, the super-saturation will have vanished; but if it was not, it will be found to have gained in strength to some extent.

Formerly natural magnets were much used, and then their yokes and pole-pieces were arranged as is shown in Fig. 37; m, m' are plates of soft iron which are fastened against the poles and are terminated by thicker lumps p, p', called the pole-pieces, where the effective poles

of the magnets are situated. The armature C is placed across these, and is terminated by a hook by which a weight is supported. Other plates of copper bind the plates of soft iron m, m', to the mass of magnetic oxide.

FIG. 37.—Natural magnet armed with pole-pieces

§ 3.—*Jamin's Magnets—Lifting Power of Magnets.*

In the latter part of the last chapter we described M. Jamin's work on the distribution of magnetism in magnets and his new rules for the construction of magnets; we will now proceed to describe some of the details, and to give some of the results obtained.

Having discovered that the strength of a magnet increases with the size, but in a less ratio, M. Jamin built up his magnets of pieces of ribbon steel. By using a sufficient number of layers he was able to make normal magnets, that is to say, magnets having the maximum strength with the least weight, and thus he produced magnets which would lift twenty times their own weight (Fig. 38).

The effect of armatures and contacts on magnets has also been carefully studied by M. Jamin.

Suppose we take several strips of steel and magnetise them to saturation separately; it will be found if we build a magnet up with these that the power will increase steadily until we reach a certain limit, namely that of the normal magnet. Suppose this number of strips be ten. Now let us again start building our magnet with the same strips, but using two pole-pieces with large surfaces, it will now be found that the power increases at a slower rate, but that the maximum is not reached until we have used a greater number of

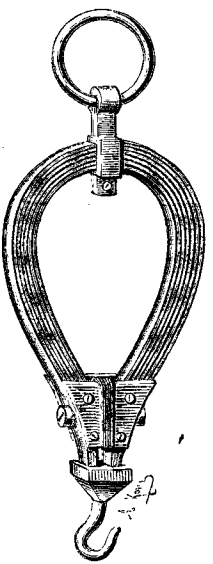

FIG. 38.—Jamin's horseshoe magnet.

strips. Thus the total force is increased by the pole-pieces. M. Jamin says he made a magnet of three strips with no pole-pieces which had a lifting weight of 4 kilograms, but that using the same strips but with two pole-pieces, 350 centimetres square, it attained a lifting weight of 140 kilograms. It is an essential point however to magnetise the strips separately, and to arm them with their pole pieces afterwards. They should not be magnetised after being put together.

The following conditions are laid down by M. Jamin, as essential when it is required to make the best possible magnet out of steel strips of a given length.

1st. The pole-pieces ought to absorb the whole of the exterior magnetism: to do so they must have a large mass.

2nd. This mass being given, the surface of contact ought to be reduced until the free magnetism of the magnet after contact begins to increase.

3rd. When the length and breadth of the strips are fixed, the number should be sufficient to allow a little free magnetism to appear on the magnet when the armature is in contact.

If the number is less than this, the full permanent effect will not be attained; but if the number is too great, then there is excess of free magnetism, which is mere waste.

4th. The armatures should be strong, fitting well, very compact, above all they must not be too heavy.

M. Jamin presented to the Academy of Sciences a magnet built up according to these laws, he then describes it: Two pole-pieces each weighing 16 kilograms, placed opposite each other, are firmly fixed by tough strips of copper, their breadth is 11 centimetres, their polar surfaces are horizontal, and at the bottom they are 12 centimetres apart. Their thickness is 20 millimetres, they are well surfaced, and hold an armature of soft iron of cubical form 15 kilograms in weight. From these surfaces the pole-pieces rise, separated from each other by an increasing interval; they gradually get thinner, and end in a sharp edge.

They are joined above by a strip of steel 1·2 metres long, which is fixed to their exterior faces, and bent by its own natural elasticity. All the other strips are placed, ready magnetised, on the inner face of this one; being left free they press themselves against the outermost strip, their ends resting against the pole-pieces. As their number is increased the lifting power also increases as follows:—

U Number of strips.	F Lifting power after first contact. (kilos)	F_1 Permanent Lifting power. (kilos)	$F-F_1$ Difference. (kilos)
20	175	154	21
30	316	280	36
40	460	376	84
45	558	460	98
50	600	475	125
55	680	498	182

"The lifting power F after the first detaching of the load is always greater than F_1, which is the permanent power; this difference increases slowly until the magnet consists of 40 to 45 strips. From this point we observe that the free magnetism is increasing at the contact surfaces. From 40 to 55 F goes on increasing, but F_1 remains almost constant, attaining as its limit about 500 kilograms: this limit cannot be passed with these pole-pieces under these conditions. So when the magnet consists of 45 strips weighing 46 kilograms, the lifting power is 460 kilograms or 10 times its own weight, but the relative power of the apparatus rapidly decreases when the number of layers is increased beyond this, since then the weight increases more rapidly than the power."

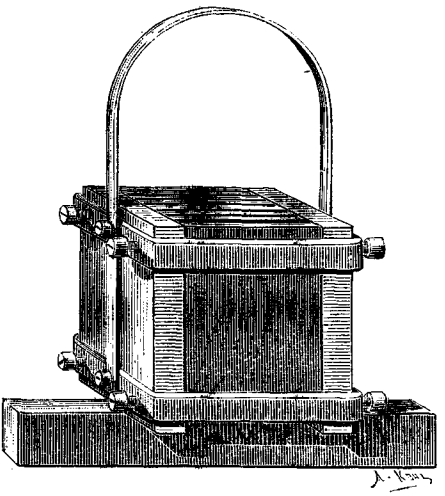

FIG. 39.—Another form of Jamin's magnet.

Experiment and theory agree in showing that it is best to have pole-pieces of a considerable perimeter and small length: but there is no use in increasing the contact surfaces beyond a certain size. The quality of the steel also causes great variation in the power of the magnets, and in the limit of normal magnetisation which, we have seen, depends also on the length of the strips. Well-tempered and carbonised steel is very difficult to magnetise, but retains its magnetism very perfectly, whilst burnt or short steel with very little carbon can be magnetised much more easily, but does not retain its

magnetism so well, being only superficially magnetised whilst good steel is magnetised throughout.

In concluding this abstract of M. Jamin's work we would call attention to figs. 38 and 39, which show two kinds of magnets constructed according to the rules laid down by M. Jamin. The first is a horseshoe of the ordinary shape made up of ribbon steel. The layers of steel that compose the bundle are sharply curved and their poles brought near together; the pole-pieces of soft iron separated by a piece of brass are strongly fixed both together and to the strips.

The second figure shows a magnet consisting of sheets of steel placed between two thick pole-pieces of soft iron; the whole is strongly held together by straps of brass. The armature is a bar of soft iron. This magnet can lift two or three times its own weight.

§ 4.—*Magnetisation by Terrestrial Induction.*

The foregoing methods of magnetisation are based on the action of a lodestone, or of a more or less strongly magnetised bar, upon strips of magnetic substances possessing retentive power. The greater its retentive power, the more powerful must the lodestone or magnetic bar be that is to magnetise it.

We know that the earth is a magnet or, what comes to the same thing, that it acts as one. We can therefore avail ourselves of it to magnetise magnetisable substances. As, however, its poles are hundreds of miles away, their effects are comparatively feeble, and the magnetic field is a comparatively weak one. Consequently the direct action of the earth will communicate magnetism to those bodies which have a feeble coercitive force, such as soft iron and untempered steel. These suppositions can be proved; for experiment shows that the action of the earth is able feebly to magnetise masses of soft iron or bars of untempered steel.

If a bar of iron be placed in the magnetic meridian at the angle ot dip, or simply in the magnetic meridian (if it is vertical this second condition is of necessity fulfilled), the lower part will become a north-seeking pole and the upper part a south-seeking pole. This we can easily prove by bringing a compass needle near to each end; the north

pole of the needle will be attracted by the upper end and repelled by the lower.[1] This magnetism ceases as soon as the bar is moved from the magnetic meridian, but if the bar be struck endwise, whilst vertical, with a hammer, a portion of the magnetism is rendered permanent. The same thing occurs every time that soft iron, thus magnetised by the earth, is subjected to any blow or stress that will assist the particles in turning round under the influence of the weak magnetising force. Thus is explained a well-known fact, that in workshops where iron is worked a great many tools became magnets. Gay-Lussac was the first to observe that if a bar was twisted when in a vertical position it could be rendered a powerful magnet. Bars of iron which have been exposed to the air for some time in a vertical position become true magnets, for example, shovels, pincers, fastenings of windows. Every smallest vibration helps to increase the gradually growing magnetism of such bodies.

The first observations of this kind have been attributed to one Julius Cæsar, a surgeon of Rimini, about 1590. Crosses upon the tops of spires are very good examples of magnets formed under these conditions. Gassendi in 1630 found the cross of the church of St. John at Aix, which fell from being rusted through at the base, to be a magnet. Several examples are also given in the *Encyclopædia* of D'Alembert and Diderot of church crosses, at Delft, Chartres, and Marseilles, that had become magnets.

We shall in another place describe magnetisation by the electric current, but it has been known for a long time that lightning could make magnets. The article on the magnet in the above-mentioned *Encyclopædia* says: "The lightning one day struck a room in which was a case of steel knives and forks for use at sea. The lightning entered at the south angle of the room near the case. Several knives and forks were burnt or broken, whilst those that were left were strongly magnetic, and would lift large nails and iron rings. This magnetic virtue was so strongly impressed upon them that the only means of getting rid of it was to heat them to redness."

[1] To be sure that the bar has not been previously magnetised, turn it vertically end for end; then again the north-pole should be repelled by the lower end.

§ 5.—*Astatic Arrangements of Needles.*

In certain cases it is desired to arrange a magnetic needle so that it is not acted upon by the earth's magnetism. There are several ways of doing this: for example, by placing a compensating magnet at a suitable distance, in such a position as to neutralise the earth's magnetic force on the needle. Another way is to so pivot the needle that its axis of rotation is the line of dip at the place: the earth's magnetic force will then have no tendency to make it rotate round this axis. Another way is to place two equal and equally strongly magnetised needles end to end in one line with their similar poles

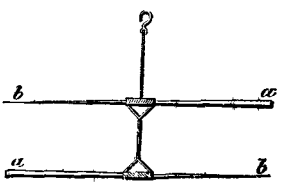

FIG. 40.—Astatic pair of needles.

together, the line of pivots passing through the middle double pole. The usual way of constructing an *astatic pair of needles* is depicted in Fig. 40. Two needles having equal magnetic moments are set parallel to one another upon a rigid connecting-piece, their poles being turned in opposite directions. Such an astatic pair is employed, as we shall see, in constructing certain kinds of galvanometers.

CHAPTER IV.

TERRESTRIAL MAGNETISM.

§ 1.—*First Ideas of Terrestrial Magnetism.*

PEOPLE in olden time had no other knowledge of the magnet than its attractive power; having no idea of the directive action of the earth, or, in other words, of the tendency of a magnet freely suspended to point in a constant fixed direction. Their first knowledge of this in the western world dates from the introduction of the compass from the East where it had been in use for ages.

From the most remote antiquity, the Chinese[1] have, it is claimed, used the compass to guide them in their travels whether on land or water. At least they used an invention which they called "south-indicating cars" ("tchi-nan"). The upper part of these magnetic cars consisted of a needle floating freely on water, and moving the arm of a small figure pointing to the South. Like several other inventions of the same origin, the compass dates back through many centuries before either the Greeks or the Romans, or the Phœnician or Etruscan navigators had made use of it.

It was without doubt introduced into Europe by the Arabs in the eleventh or twelfth century in its original form of a needle

[1] Edward Biot mentions two traditions of ancient Chinese authors of the fourth and twelfth centuries of the present era. The first tradition refers to the invention and the use of the south indicator car to the sovereign Hoang-ti during, what is calculated to be, the twenty-seventh century B.C. According to the second tradition, it is accredited to a prince Tcheon-Kong, in the eleventh century B.C. Thus, Humboldt remarks, the property of the needle showing north and south was used in times which perhaps preceded the Dorian invasion, and the return of the Heraclidæ to the Peloponnesus.

floating on water. The balanced compass needle only came into use in the latter half of the fourteenth century.

The first mention of the declination of the compass,—that is to say, its variation from pointing to the geographical north,—is also due to the Chinese. As a matter of fact in the extreme east there is very little declination, and this remains constant or nearly so for centuries. So it was very difficult to determine the existence of the declination with such rough apparatus. Another passage from an ancient Chinese author quoted by M. Biot shows that this was not discovered until near the end of the eleventh century. From the same source we learn that the Chinese magnetise their needles by rubbing them with a piece of lodestone. The following is an account of the process: "Those who perform the trick rub the needle with a magnet-stone; then it will mark the south; it will, however, decline always a little toward the east. It does not exactly indicate the south. When such a needle floats on water, it is very much agitated; if one's finger-nails simply touch the edge of the basin where it floats, they throw it into agitation. It is better to suspend it in order to manifest its virtue as much as possible. This is the method: Take a thread out of a new skein of cotton and stick one end of the thread to the exact middle of the magnet with a piece of wax as big as a mustard seed. Then hang it in a place free from draughts. The needle will then point steadily to the south. Among these needles obtained by rubbing there are always some which mark the north. Our conjurors always have some which point south,[1] and some which point north."

The above paragraph shows that the Chinese anticipated Gilbert and Coulomb in the use of a needle suspended about its centre of gravity; only they made no great use of it.

We have seen above how the introduction of the compass into European navigation preceded by two or three centuries only the great expeditions by land and voyages by sea, the result of which was the enlargement of the old world and the discovery of the new. The introduction of the compass singularly favoured the exploration of the globe; it was, one may say, the starting-point of geographical

[1] This curious distinction between needles which point south and those which point north, probably arises from the ignorance of the Chinese of the fact that every magnet has two opposite poles.

discoveries, but it is also the foundation-stone of an important branch of physics, that of terrestrial magnetism. It is to Gilbert that the first idea of the earth as a great magnet having poles and a neutral zone is due; but Christopher Columbus before him knew of the declination of the compass needle, and that this varied from one place to another. The great navigator also recognised the existence of a line of no declination situated a little to the east of one of the Azores.

Gradually, by the collection of facts, useful generalisations are arrived at, and then definite laws can be drawn up, and from these scientific theories are formed which take the place of vague and absurd speculations.[1]

§ 2.—*Magnetic Declination.*

The effect of the discovery of the compass on long distance navigation, and thus on geographical discovery, was immense, and is too well known to need comment. Nor is its purely scientific value less, for, as we shall see, by employing special and perfected magnetic instruments, we are able to obtain precise data on the magnetic state of the earth. In this study there are three elements to be determined for each place; they are the declination, the dip, and the magnetic intensity. The first two we have defined, but the third one we will define when we describe its measurement, which is a difficult problem. A great number of observations taken simultaneously all over the earth have to be combined and tabulated so as to give the distribution of the earth's magnetism at that time. Again, it is necessary continually to repeat the observations with the same apparatus or with similar apparatus, so as to give comparable results, in order to demonstrate the changes in the magnetic elements of each place, and to study the laws which govern these variations with time. However, thanks to navigators, savants, and scientific expeditions, we are now in a position to map out the distribution of

[1] According to Maurolicus, "if the magnetic needle did not point directly north, the reason was that it was affected by a magnetic island situated beyond, and by the side of the north-pole." (Henri Martin's *Thunder, Electricity and Magnetism, according to the Ancients.*)

the earth's magnetism, and fix the more important variations, from the great number of observations made in all parts of the world.

Let us now see how the three elements, declination, dip, and intensity, are measured.

We will first describe the *declination compass.*

When it is required to measure the declination with extreme accuracy the compass is constructed as is shown in Fig. 41. The needle is balanced on an agate centre in a circular box MN, which carries on two supports a telescope LL′, having cross wires in its eyepiece; this is moveable about a horizontal axis *aa′*, but the

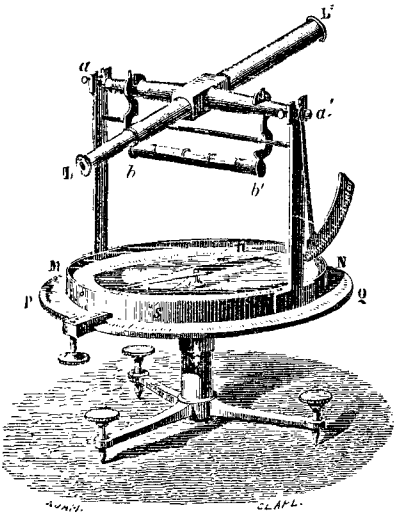

FIG. 41.—Declination compass.

whole arrangement can also be turned in a horizontal plane above a divided circle PQ.

To measure the declination the compass is placed on a firm stand, and is then carefully levelled by means of the spirit level NN. This being done, the telescope is then directed to some well-known star, the time being accurately observed. Now by reference to astronomical tables the exact position of the star is known, and from that we can calculate the angle the telescope makes with the meridian. The compass box is then turned through this angle so that the readings 0°—180° are in the meridian. Then by carefully reading

the angle which the compass needle makes with the meridian we have at once the magnetic declination.

The same method is used with Gambey's compass (Fig. 42) which admits of still greater accuracy. In this compass the needle

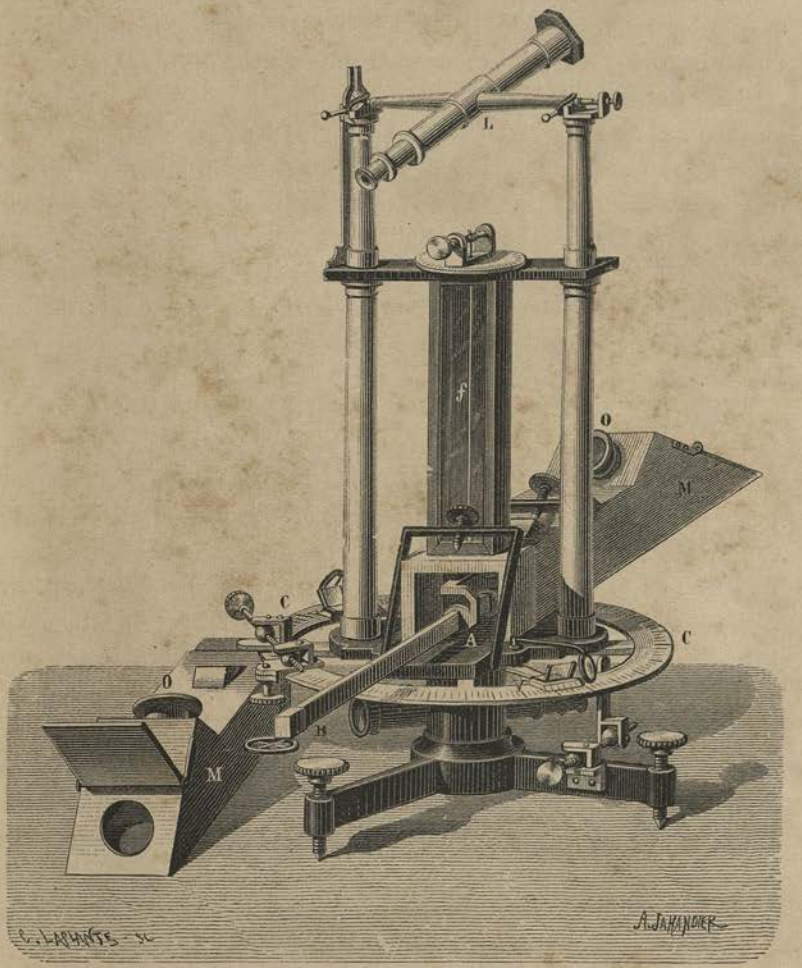

FIG. 42.—Gambey's declination compass.

is a bar AB which carries at each end a ring with cross wires. The magnet is suspended by a bundle of torsionless silk threads fastened at the top to a screw. The frame supporting the screw carries a telescope which is used in the way above described. This frame

which carries the telescope and magnet can turn on a vertical axis over a graduated circle CC. By the aid of verniers the necessary readings can be made for determining the position of the star and also the position of the axis of the magnet.

To eliminate the disturbing effects of currents of air, the silk suspension is enclosed in a glass case MM, and the magnet is also boxed in, and observations are made through the openings OO.

The determination of the absolute declination with such an instrument as we have just described, is a very long and delicate process, especially as the needle is subject to perceptible minute variations during the experiments. The result that is obtained is the mean of the true values of the declination during the experiments. In magnetic observatories the absolute declination is rarely observed, but observations of its changes only are taken from day to day; for this purpose an instrument called a *variation compass* or *declination compass* is used.

The following is the description of the compass used at Montsouris for observing the variations in declination. It consists of a copper frame, supported on a base of marble (Fig. 43), the two side faces being of glass. Rising from the centre of the top of the frame is a copper tube, on the top of which fits a cap, which is graduated round its edge and provided with a clamp. In the centre of the cap is a rack and pinion and a clamping screw. The suspending thread of the needle is attached to the rack. The magnet is a bar of steel 96 mm. long, 10 mm. deep, and 2 mm. thick. The magnet has been strongly and regularly magnetised by an electric current, it is fixed parallel to a mirror which carries the hook by which it is suspended. The needle swings freely in a cylinder of copper 50 mm. high and 7 mm. thick, which is intended to deaden the oscillations of the magnet by the inductive action of the magnet moving in the copper envelope. This cylinder carries a mirror for comparison. The declination compass is fixed on a stone pillar in the interior of the magnetic observatory; there is a second stone pillar similar to the first supporting a reading-telescope and scale (Fig. 44); the distance between the two pillars being 1·719 metres. The scale is fixed at right angles to the axis of the telescope, and is divided into millimetres. The telescope has at the focus of its eyepiece a vertical wire to serve as a sight, and gives an image of the scale reflected by

the mirror. This image is moved through double the angular displacement of the mirror. The distance of the scale from the mirror,

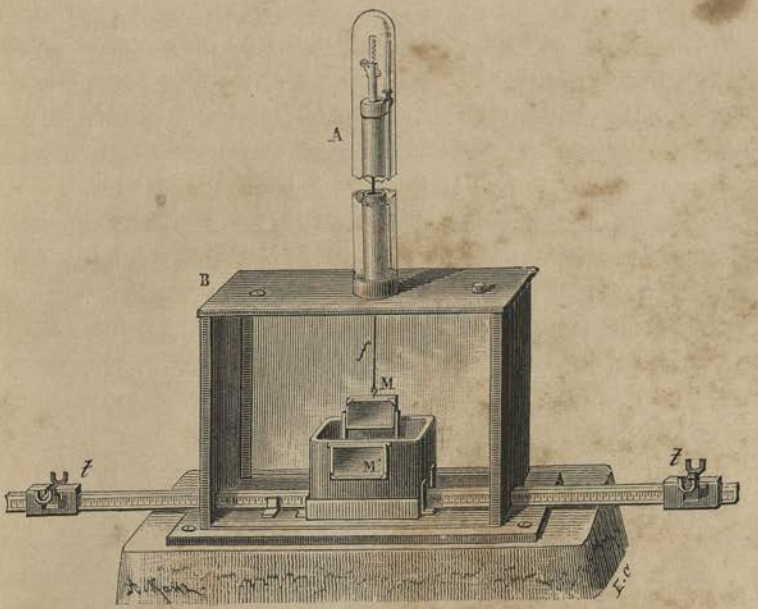

FIG. 43.—Declination compass as used at the Observatory of Montsouris.

1·719 metre, has been so calculated that the movement across the field of the telescope of 1 mm. is equal to a motion of the mirror through

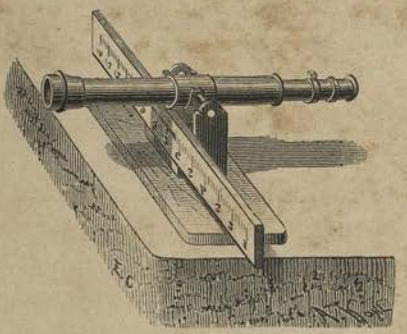

FIG. 44.—Observing telescope and scale.

1 minute of arc. So that the motion of the mirror can easily be read to 0·1 minute of arc.

§ 3.—*Dip and Magnetic Intensity.*

When a magnetised needle is suspended by its centre of gravity we know that it can move in any position about that point, but that it at once places itself in the magnetic meridian, making a fixed angle with the horizontal, called the *angle of inclination* or "*dip*" for that place at that time. If the needle be arranged so that it can only turn on a horizontal axis through its centre of gravity, it generally takes up a position inclined to the horizontal, but which varies with the vertical plane which contains the needle. When the needle is in the meridian it makes its minimum angle (Fig. 45) with

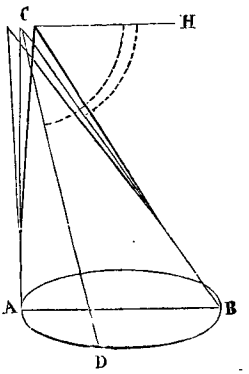

FIG. 45.—Diagram showing the maximum and minimum angles made by the dipping needle with the horizon. Angle HCB is the minimum angle or true dip; angle HCA the maximum angle, when the axis is perpendicular to the magnetic meridian.

the horizontal, this is the angle of dip or inclination, for that place at that time; if the needle be now turned from the meridian the dip continues to increase until the needle is at right angles to the meridian when it sets itself in a vertical position.

We will now describe a *dipping needle* or *dip compass* (Fig. 46) which is a special instrument for measuring this property. A vertical graduated circle carries at its centre a needle which turns about a horizontal axle which passes through the centre of gravity of the needle, and is situated at the centre of the circle; this axle rests on two agate bearings carried by two horizontal supports across the

divided circle; the whole arrangement, which is supported by two pillars, is capable of being turned upon a vertical axle, which forms the support of the instrument; a second horizontal circle being fixed so as to measure the angle of the first circle with the meridian. By means of levelling screws and of a spirit-level, the second circle may be brought into a horizontal plane, thus adjusting the verticality of the plane of the needle. When this has been done, the position of the magnetic meridian has to be determined, this can be done in two ways. Firstly, by finding the position which gives the smallest angle of the needle with the horizon; this gives the meridian at once. Secondly, by finding in what position the needle is vertical; in this

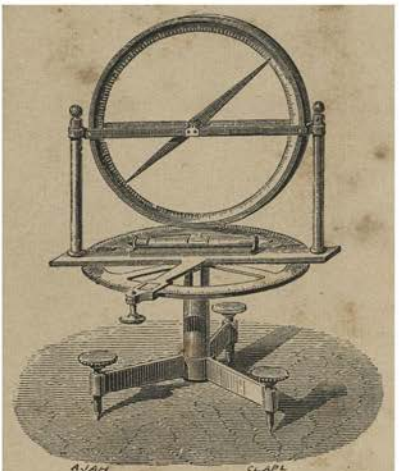

FIG. 46.—Dipping needle.

case the horizontal axis of the needle is at right angles to the meridian; hence by turning the instrument through 90°, the needle is brought to the meridian and the reading may forthwith be taken upon the vertical circle.

It rarely happens that the needle is perfectly magnetised: one of the poles may not be exactly at the end; in that case a second reading is taken with the needle turned over so that the upper edge is in the place of the lower; the mean of the two readings then gives the inclination free from that error. A second source of error is in the fact that the centre of gravity of the needle may not be at the point of rotation of the needle. In this case the weight of the needle will

affect the angle of inclination. This error can be eliminated by remagnetising the needle in the reverse way when the poles have changed places. The inclination is again observed with the remagnetised needle, two new readings being taken.

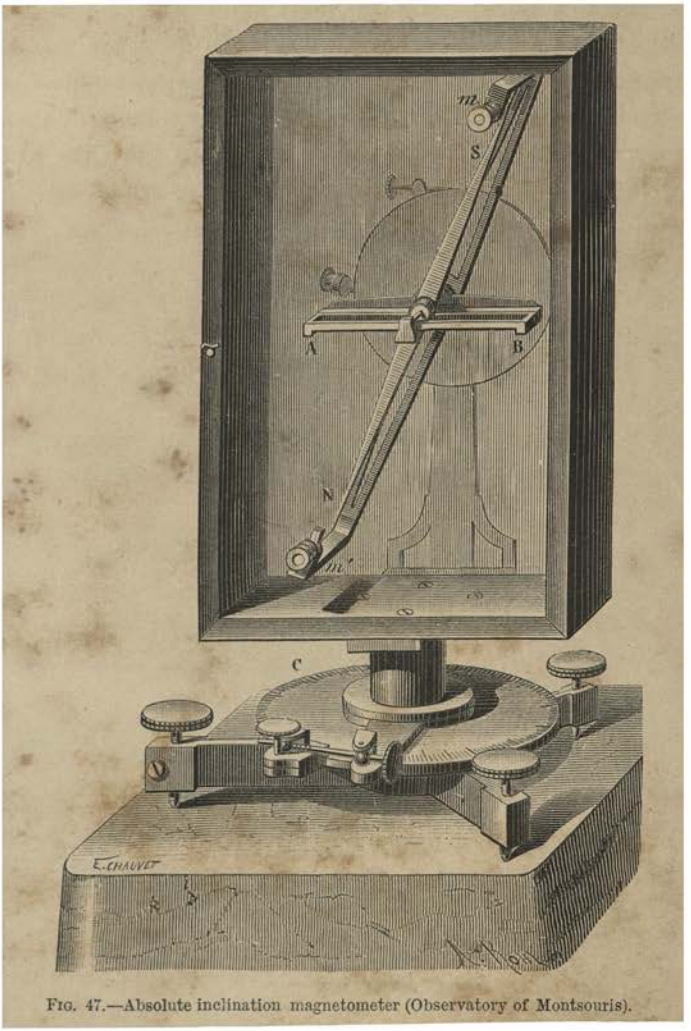

FIG. 47.—Absolute inclination magnetometer (Observatory of Montsouris).

The mean of these four readings then gives the true inclination at that time, and in that place where the readings are made.

If it is desired to observe the variations in inclination at all times

of the day, special magnetometers for observing the variation in inclination are used. Figs. 47, 48, and 49 represent the absolute inclination magnetometer and the magnetometer for observing variations in inclinations such as are used at the Montsouris Observatory.

The following is the description of the absolute inclination compass as given in *l'Annuaire météorologique*. It consists of a horizontal graduated circle supported by three levelling screws; from the centre of which circle rises a support for a case which contains the needle and the divided circle with its microscopes; Fig. 47 shows the face of this circle, the back only being shown in Fig. 48.

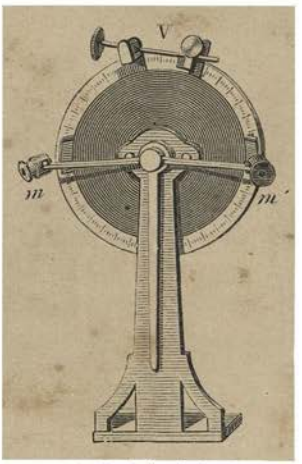

FIG. 48.—Hinder circle of the inclination magnetometer.

The needle SN is a very tapering lozenge, its length being 402 millims, and its thickness 1·3 millims. Its ends are very fine points which are observed directly by the microscopes m, m'. Its pivots are 1·0 millim diameter and are finished with extreme care, the same care being bestowed on the agate plates on which they rest. The microscopes are moveable around the vertical divided circle and serve to measure the inclination. In order to observe the needle whilst it is swinging, the microscopes are provided with micrometers consisting of a slip of glass, at the focus of the objective, divided into tenths of millimetres on each side of the central line. Each division of the micrometer is equal to 2′ 20″ and is divided by the

eye into ten parts. The reading of the needle may therefore be made accurately to about $\frac{2}{10}$ of a minute. On the other side, the graduated circle, V, which measures the inclination of the microscopes, is itself read to the $\frac{2}{10}$ of a minute, so that there is a uniformity in the degree of precision of the two readings. The remarks on the number of separate operations which are necessary for getting accuracy in the measurement of the absolute declination also apply to measuring the absolute inclination. In magnetic observations

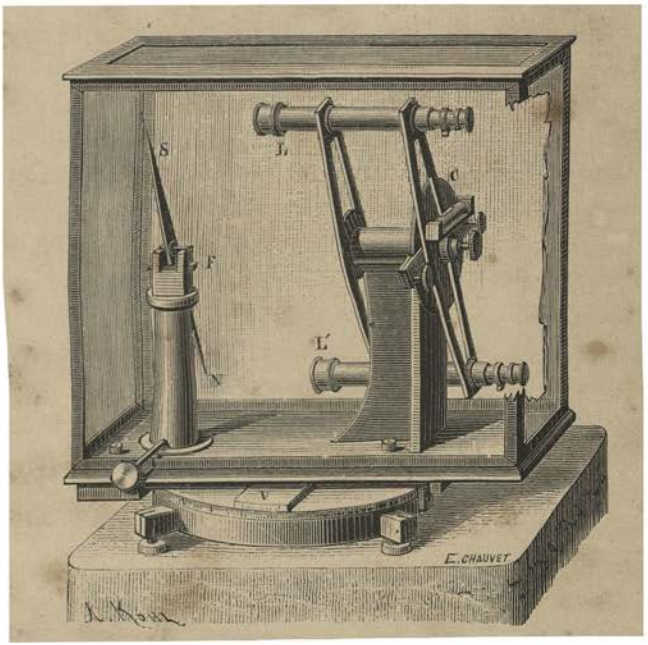

FIG. 49.—Magnetometer for observing variations of inclination (Observatory of Montsouris).

these exact measurements are on this account only made from time to time. The daily observations are, on the contrary, purely on the variation of these elements, and are much easier and more rapidly made with "variation" magnetometers.

There is a third element, the determination of which is of very great importance in the study of terrestrial magnetism, namely the *intensity* of the force which acts on the needle; that is to say, the total resultant of the magnetic actions exercised on that needle by the earth.

The declination and inclination combined give the oblique direction of the magnetic force due to the earth; but this gives us no information as to the variations which may arise in the *amount* of the force itself, from place to place and from time to time.

The method of determining the magnetic intensity is founded on the comparison of the oscillations of a needle very slightly deflected from its position of equilibrium, with the oscillations of a pendulum. Observation proves the oscillations of the needle to be isochronous, that is to say, each swing occupies the same time as the preceding swing. We may, therefore, conclude by the mathematical laws of oscillation that the magnetic forces which produce them vary inversely as the square of their period, or in other words are proportional to the squares of the numbers of oscillations made by the same needle in the same time. Let us then take a magnetic needle and make it oscillate about its centre of equilibrium and let us afterwards take it to another place, counting in each case the number of oscillations made in a given time. The magnetic intensity of the two places will vary as the squares of the numbers of oscillations at the two places.

This process may be applied either to an inclination or to a declination needle. If the first, care must be taken that it is in the magnetic meridian; if the second case, it will be observed that the needle does not lie in the oblique direction of the magnetic force and therefore in this case the oscillations will be due solely to the horizontal component of that force. By the aid, however, of a simple mathematical formula, it is easy to find from the components the total intensities of the forces themselves. The horizontal component must be divided by the cosine of the angle of dip to calculate the total intensity.

For making such observations with very great nicety recourse is had to special forms of magnetometer known as *intensity magnetometers*. We should be deviating from our course to describe such apparatus as well as the delicate operations in which it is employed. It is sufficient for us to say that with Gauss's bifilar magnetometer the horizontal component of the earth's magnetic force has been determined to within $\frac{1}{20000}$ of its value.

Humboldt gives the following history of the first scientific determinations of the magnetic elements of the globe. "The oscillations," he says, "the period of which is the measure of magnetic

intensity, became for the first time the subject of experiment towards the end of the eighteenth century, and it is only in the earlier half of the nineteenth century that this subject has been thoroughly and perseveringly investigated. In 1723, Graham measured the oscillations of an inclination needle to see if they were constant, and to discover the relation to gravitation of the force which produces them. The first attempt to determine the value of the magnetic intensity at various points on the earth's surface by the method of oscillations was made by Mallet in 1769. He found, with his very imperfect apparatus, that the number of oscillations was exactly the same at St. Petersburg lat. 59° 56′ as at Paris lat. 48° 50′, from which he judged, and so it was accepted until the time of Cavendish, that the intensity of the earth's magnetic force was equal all over the globe." Lemonnier and Borda avoided this error, which was soon rectified by the more perfect observations of Lamanon (1785-1787), and afterwards by those of Humboldt himself (1798-1829) in the tropical parts of the New World and in Eastern Asia.

Since then continuous observations have been made on all three elements in all parts of the world. These have come from observatories founded in all parts of the world, where special registering instruments are used that include all such phenomena and at the same time admit of the study of the laws of their variations. We will go into some details with respect to this matter.

The observations of the magnetic elements with such apparatus as we have just described requires a great deal of time and labour, and the values of these elements can only be given at disjointed intervals of time. In special observatories, fixed hours are chosen for making the observations, such as six o'clock in the morning, noon, six o'clock in the evening, and midnight. For some time now in the principal observatories, registering instruments have been set up, so that a continuous record is kept both day and night of the variations of declination, of the horizontal and vertical intensities, and also of the inclination.

The following is, according to Gordon, the principle of the registering instruments at the observatory at Kew :—

"A mirror is attached to the moving magnet, and a spot of light from a lamp thrown by it on a piece of sensitized photographic paper moved continuously by clockwork. If the magnet remains at rest, a

straight line is traced; if it moves, a zigzag line. Three elements are observed, *viz.* :—Declination, horizontal force, vertical force. From the ratio of the last two of these the inclination can be calculated, so it is not observed separately."

Figs. 50, 51, and 52, show parts of the apparatus for registering the declination and the horizontal force, as well as the cylinders moved by means of clock work upon which the curved trace is registered photographically by the light reflected from the mirrors

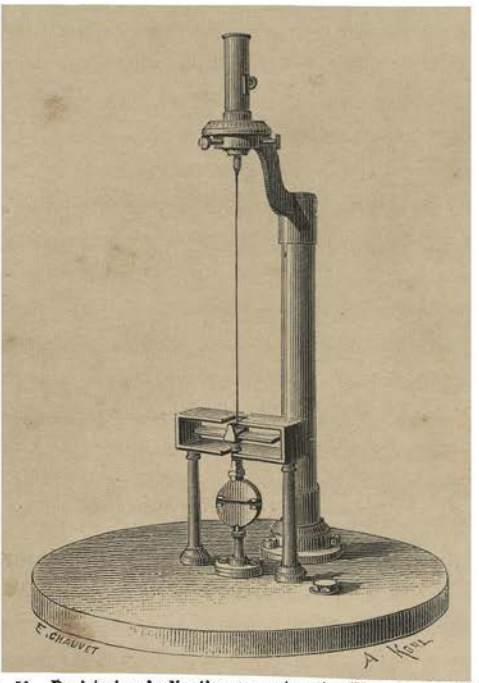

FIG. 50.—Registering declination magnetometer (Kew Observatory).

"The portion of the apparatus which records the declination consists of a suspended magnet with a mirror attached; the magnet being hung by a single fibre as in the unifilar magnetometer. It stands on a massive stone pier. Light from a gas-lamp passes in through a slit and collimating lens, falls upon the mirror, and is then reflected inside a wooden tube into the box which contains the barrels and clockwork shown in Fig. 52. The light falls on one of the horizontal barrels. Round this barrel is fastened a sheet of

sensitized paper. If the barrel were at rest and the magnet moved

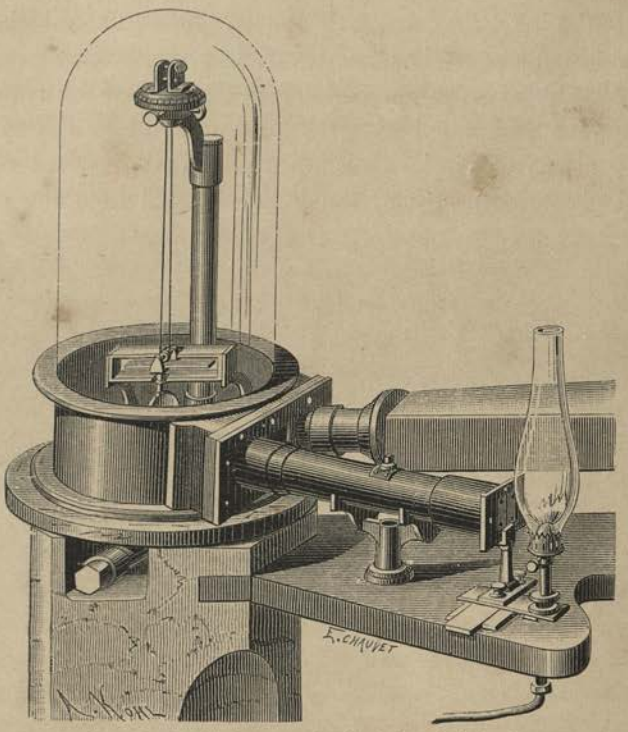

FIG. 51.—Registering apparatus for horizontal intensity.

a black line would be traced on the barrel parallel to its axis, and of

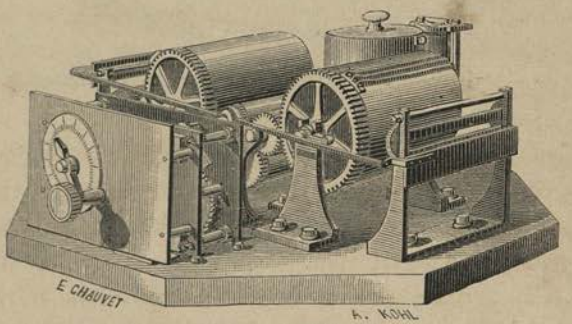

FIG. 52.—Cylinder and clockwork of the registering apparatus.

a length corresponding to the extreme motions of the magnet. If

the magnet remained at rest and the barrel revolved, a line would be drawn round the barrel, which, when the paper was unrolled, would be a straight line perpendicular to the axis. When, however, the clock moves the barrel steadily round, and the magnet oscillates at the same time, an irregular curved or zigzag line is traced round the barrel, the distance of any part of which from the base line gives the direction of the magnetic meridian at the corresponding time."

Fig. 58, p. 77, is a reproduction of two registered curves of the horizontal force on two consecutive days, recorded at Kew, on that part of the cylinder on which are inscribed the variations of horizontal force. The magnets are suspended in globes from which the air is exhausted.

§ 4.—*Periodic Variations of the Elements of Terrestrial Magnetism: Inclination, Declination, and Intensity.*

For a long time, in spite of the discovery of declination, it was believed that the needle pointed to the north; and in fact it is barely two centuries since there was no declination in western Europe. There was none in London in 1657, and in Paris about 1666. Before this time the declination was easterly, and observations show that it was steadily decreasing. But in Paris as in London from about the years 1666 and 1657 the needle has been gradually gaining towards the west, the easterly declination having now become westerly. The value was continually increasing until in 1814 and 1815 it had reached its maximum, but now it is gradually coming back towards the true astronomical north. These variations are shown in a curve in Fig. 53, and in the following table, p. 70.

These secular variations occur all over the world. Let us take as an example in the southern hemisphere, the Cape of Good Hope, where the declination in 1605 was easterly, and about half a degree; it was 0° some years later, and from 1609 it has gradually increased in a westerly direction; in 1791 it reached its maximum of about 25° 40′. But what are the laws that govern these variations? Are their amplitudes the same in different places, and have they similar periods? These are questions that cannot be answered in the present state of our knowledge.

MAGNETIC DECLINATION.

THE VARIATIONS IN PARIS AND LONDON FROM THE MIDDLE OF THE SIXTEENTH CENTURY UP TO THE PRESENT TIME.

Years.	Paris.	London.
	° ′	° ′
1550	8 0 E.	— —
1580	11 30	11 17 E.
1622	6 30	6 12
1634	4 16	4 5
1657	— —	0 0
1664	0 40	— —
1666	0 0	0 34 W.
1667	0 15 W.	— —
1672	— —	2 30
1700	8 12	9 40
1720	13 0	13 0
1740	15 30	16 0
1760	18 30	19 30
1790	22 0	23 39
1800	— —	24 36
1806	21 51	24 8
1814	22 34	— —
1815	— —	24 27
1820	— —	24 11
1831	— —	24 0
1835	22 24	
1850	20 31	Kew.
1858	19 36	21 54 W.
1863	19 0	21 13
1868	18 24	20 33
1873	17 33	19 58
1878	17 6	19 14
1879	16 56[1]	19 7

[1] The decrease of the mean annual westerly declination at Paris and throughout France is 9′. Taken since the maximum in 1814 it is barely 5′; from 1580 to 1666 the mean annual decrease was 8′. The annual increase from 1666 to 1814 was 9′.

Distinct from these secular variations we find also yearly variations and daily variations.

The daily variations were observed for the first time at Louvo (Siam) by Hellibrand and Father Tachard; they were also studied by Graham from the year 1722. Humboldt gives the following description of the daily movements of the needle. "In the lower latitudes of the northern hemisphere the needle points nearest the true north at a quarter past eight in the morning. From a quarter past eight in the morning to a quarter to two in the afternoon the

needle moves from east to west, when it reaches it most westerly position. This movement to the west occurs all over the northern

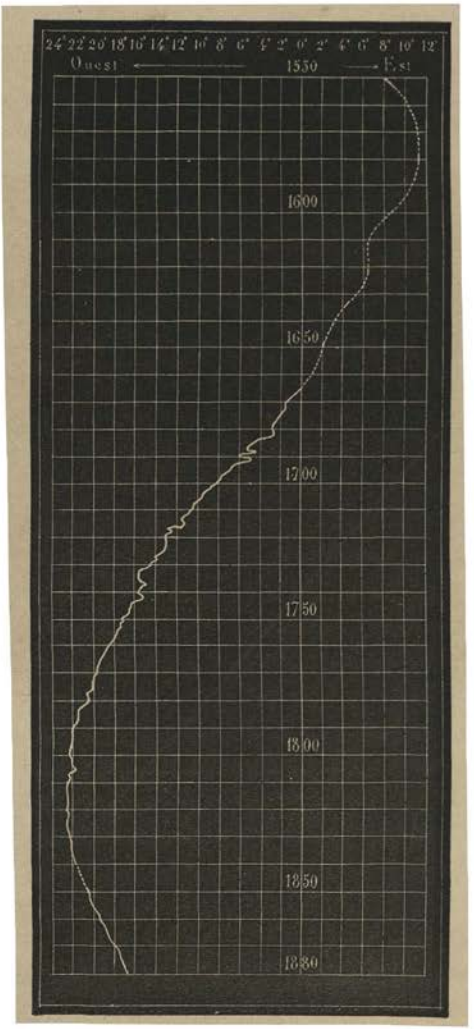

FIG. 58.—Secular variations in the declination at Paris, from 1550 to 1880.

hemisphere, whether the declination is westerly, as in all Europe, as at Pekin, at Nertschinsk, and at Toronto in Canada, or whether it

is easterly, as at Kasan, at Sitka in Russian America, at Washington, at Marmato in New Granada, and at Payta on the coast of Peru. Starting from a quarter to two, when at its most westerly position, the needle retraces its steps towards the east during the evening and part of the night until midnight or one o'clock in the morning. It often, however, makes a slight pause about six o'clock in the evening. During the night the needle again turns to the west, very slightly,

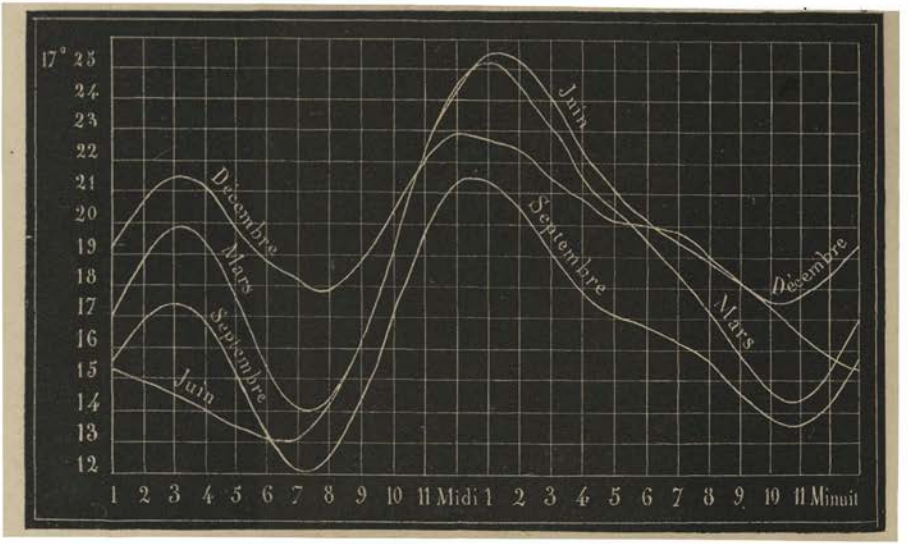

FIG. 54.—Diurnal variations in the declination: hourly means.

but is at its most easterly position at a quarter past eight in the morning."

These hours are not, however, absolutely the same in all countries, nor are the amplitudes of the oscillations equal. Observations made at Montsouris show that the maximum deviation in the middle of the day is a little nearer noon in winter than in summer; the minimum in the morning is nearer eight o'clock in the winter and seven in the summer. The amplitude of the daily variations depends on the latitude, in high latitudes it is as great as 15′ (at Paris it is only 10′); whilst near the magnetic equator it is only 3′ or 4′. These variations occur in the southern as well as in the northern hemispheres at about the same time; but the directions

are reversed. Thus whilst the north pole of the needle is moving to the west in the northern hemisphere it is moving to the east in the southern, and *vice versâ*.

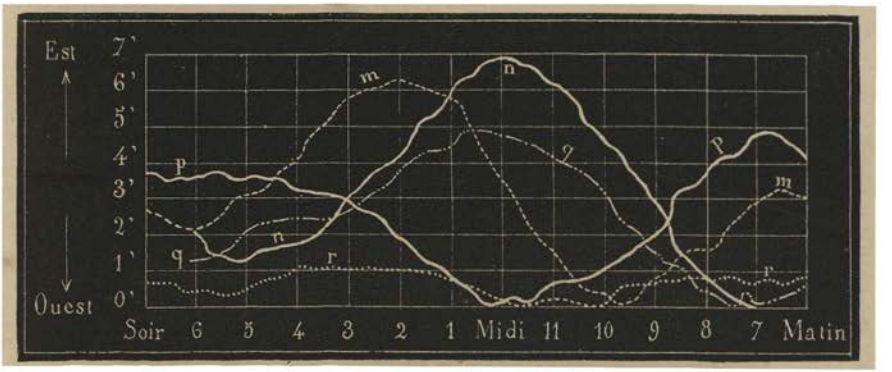

FIG. 55.—Diurnal variations in different places; *m*, at Mauritius; *h*. at St. Helena; *p*, at Offah; *q*, at Ascension; *r*, at Payta.

The declination also varies at the same place according to the season of the year. To determine these variations the following method

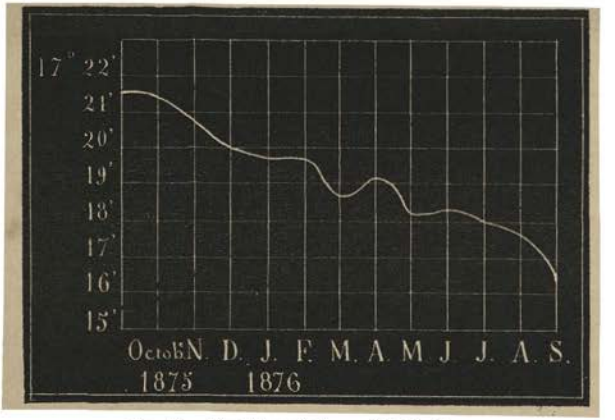

FIG. 56.—Monthly variations of declination.

is employed:—From the hourly observations of each day a mean of that day is obtained (at Montsouris a mean is taken from the observations at

six o'clock in the morning, noon, six o'clock in the evening, and midnight), and for each month the mean is taken of all the days for that month.

Comparison of the monthly means has shown, in the northern stations, that the needle moves to the west from May to September, whilst it moves back from September to May. This is the inverse of what occurs in the southern hemisphere.

If the amplitudes of the secular and annular variations be compared, so close an agreement is found that Arago concluded that they

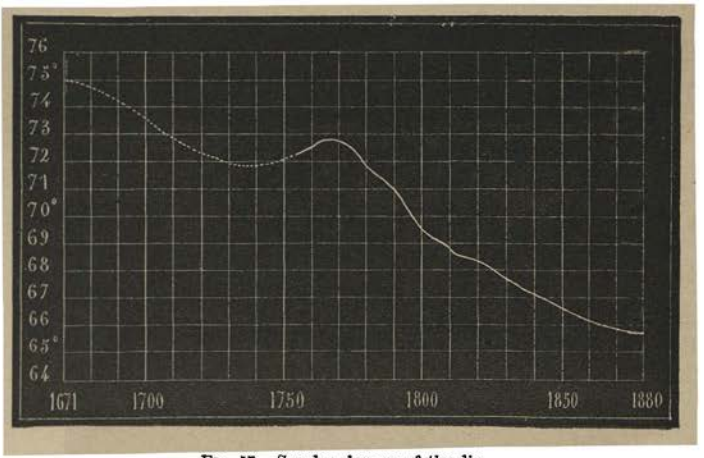

FIG. 57.—Secular changes of the dip.

increased and decreased through the same periods. The annular variations of declination were first known and studied by Cassini, Gilpin, and Beaufoy, at the end of the eighteenth and the beginning of the nineteenth century.

Inclination, or dip, is, like declination, subject to periodic, secular, annular, and diurnal variations. The table given below gives the values of this element at Paris and London from the earliest observations down to the present time and will suffice also to show the secular variation.

DIP OF THE MAGNETIC NEEDLE.

Years.	Paris.	London.
	° ′	° ′
1576	— —	71 50
1600	— —	72 0
1671	75 0	— —
1676	— —	73 30
1723	— —	74 42
1754	72 15	— —
1780	71 48	72 8
1790	— —	71 33
1791	70 52	— —
1800	— —	70 35
1810	68 50	— —
1818	68 26	70 34
1821	— —	70 3
1822	68 19	— —
1828	— —	69 49
1829	67 45	— —
1835	67 24	— —
1838	— —	69 17
1850	66 37	— —
1854	— —	68 31
		Kew.
1859	66 11	68 12
1863	66 1	68 2
1868	65 45	67 52
1873	— —	— —
1875	65 37	— —
1876	65 36	— —
1879	65 33	67 42

These numbers both for London and Paris show a constant decrease in dip, although at London the dip was on the increase from 1576 to 1723, as taken with such instruments as they then had. The mean decrease for Paris from 1671 to 1879 is 2′·7 per annum; for the last ten years it was 2′·1. At London from 1723 to 1879 the decrease is 2′·7, just as at Paris.

According to Hansteen the mean of a large number of observations give the value of dip to be 15′ greater in summer than in winter Hansteen has also determined the diurnal variations of the dip; its value being from 4′ to 5′ greater in the morning than in the afternoon. Does the intensity of the magnetic force also vary from time to time? This is a very delicate question, and one difficult to solve by observing the oscillations of a magnet; for no magnet will keep its strength

unaltered for any length of time, much less will it then keep its strength through a great number of years. Poisson described a method, which was afterwards perfected by Gauss, by means of which the absolute magnetic force can be measured without taking into account the strength of the magnets employed; the result of his observations, made at Göttingen, was negative. On the other hand, Hansteen found both daily and monthly variations of the intensity, or at least of its horizontal component, which seem to be in agreement with the variations of dip. This result, however, does not prove any real change in the total absolute intensity. Lastly, the observations made at Kew and Greenwich have demonstrated the existence of a secular variation of this element. Whilst the horizontal force is steadily increasing, the total force on the contrary is decreasing, as the following figures will show.

Date.	Horizontal Force.	Total Force.
1848	1·716 at Greenwich.	4·791 at Greenwich.
1866	—	4·740 „
1867	1·776 „	—
1879	1·797 at Kew.	4·736 at Kew.

§ 5.—*Irregular Disturbances of the Magnetic Needle.*

Distinct from all the periodic variations that we have just described, the magnetic needle is subject to other sudden disturbances, the causes of which are still unknown, and which are often of only short duration. These disturbances are called *Magnetic Storms.* "As a result of the impetus given to navigation," says Humboldt, "and the application of the compass to geodetic problems, it was noticed at a comparatively early date that there were sudden disturbances in the direction of the compass needle accompanied by swinging and trembling. It became customary to explain this phenomenon as a particular state of the needle, which, in the *parlance* of French sailors, was said to be *infatuated* (*affolée*)."

The name *magnetic storms* has been given to these disturbances, which are frequently coincident with auroras, and, according to some

writers, with earthquakes, volcanic eruptions, and with the descent of a shower of shooting-stars.

These sudden variations more particularly affect the declination; very rarely have they been observed to affect the dipping needle.

The amplitude of the oscillations rarely exceeds 1°. Humboldt observed deviations of 14′ to 18′, the duration of each being from $1\frac{1}{2}$ to 3 seconds. But often "the amplitude and inequality of the oscillations, which passed over many divisions of the scale" (Humboldt

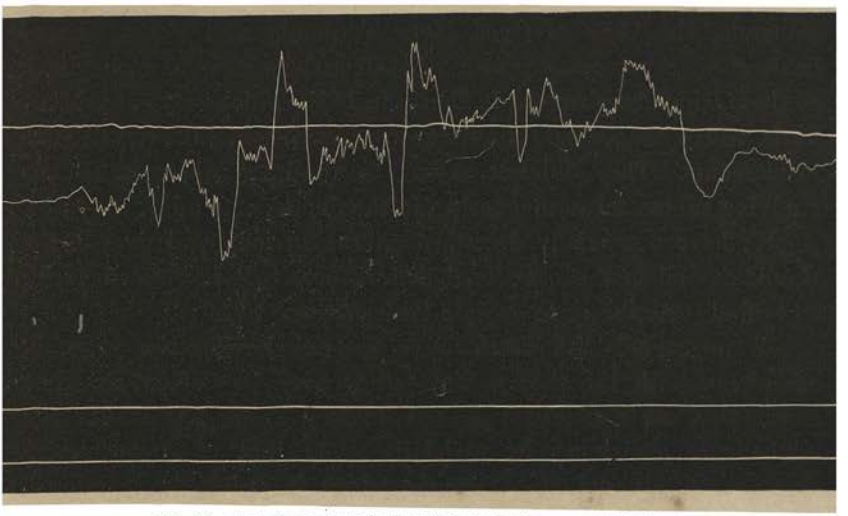

FIG. 58.—Variations of the horizontal force during a magnetic storm.

observed the needle from a distance by the aid of a telescope with crosswires) "first on one side, then on the other, rendered all observation impossible."

Although these magnetic perturbations are of so irregular a character as to be quite accidental and incapable of being predicted, it is nevertheless found that magnetic storms recur in certain fixed periods. They are twice as frequent at night, and stronger, than in the day; also more frequent and marked during the summer months from April to September than during the winter months of the northern hemisphere (according to the observations of Sabine at Toronto). In the southern hemisphere (Hobartown) their greatest

frequency is from the months of September to April, that is, also during the southern summer.

At Berlin, Humboldt observed the most violent storms and the greatest number to be about three o'clock in the morning and to cease before five. At St. Helena and at the Cape of Good Hope the greatest number of magnetic storms occur about the equinoxes.

One other remarkable fact is the occurrence of isolated magnetic storms all the world over at the same moment, even at places many thousands of miles apart. Such was the magnetic storm of September 25th, 1841, which was observed simultaneously in Canada, Bohemia, the Cape of Good Hope, Tasmania, and Macao. Humboldt cites other cases where the disturbances were more local, as those which he observed in Berlin in 1829, which only extended to Paris, where Arago made simultaneous observations with very delicate instruments. They did not extend to Freiberg, where Reich was studying subterranean magnetism in the depths of a mine.

We have now briefly described all the periodic variations of the needle as well as the occasional disturbances. It now remains with us to find some theory to explain their causes.

If we regard the earth as a magnet having two poles, in accordance with the theory first put forward by Gilbert, we must admit that its magnetism is not fixed. There then arose two methods of explaining its variability: (1) that of Halley, which supposes an internal large magnet which is being slowly rotated, thus causing the secular changes of declination and dip; (2) that of Æpinus, who considered the internal magnet fixed, but its magnetism to vary.

One thing is certain, namely, that the yearly, monthly, and daily variations belong to terrestrial time-periods, and are associated with the two movements of the earth itself, its revolution around the sun, and its rotation on its own axis. We know that the same periods affect the temperature of the earth's crust, and we also know that the magnetic power of any body is greatly affected by the temperature. Duperrey held that the variations of the magnetic needle were due to the heating effect of the sun. Biot holds that they are due to the effect of the sun as a magnetic body; our globe seeming to act as a body which is magnetized by induction. Ampère founded a whole theory of terrestrial magnetism on the supposed existence of concealed

electric currents spread over the surface of the globe and flowing from east to west. He explained by this hypothesis the general behaviour of the magnetic needle, as well as its annual and diurnal variations at different parts of the globe; the presence of the sun above the horizon, and its altitude during various times of the year, being held to explain the modifications in the electric currents, and therefore the changes in the magnetic needle.

There seems to be no doubt but that the perturbations or accidental variations of the needle are connected with another phenomenon which we shall describe in the next chapter, namely, the aurora. It is now generally allowed that this phenomenon is closely bound up with the earth's magnetism, and that magnetic storms and auroras arise from a common cause, rather than that they are cause and effect. What the cause of both may be has yet to be discovered.

Is the cause terrestrial or of cosmic origin, as the known coincidences in the simultaneous occurrence of solar protuberances and spots with auroras and magnetic storms would tend to make one think? This connection between terrestrial magnetic phenomena and the accidents of the solar surface was discovered in 1852 almost simultaneously by Sabine, Gautier, and Wolf. The following table, drawn up by an American observer, E. Loomis, shows the coincidence of the epochs of maxima and minima of the various phenomena; and the observations of Respighi and Tacchini confirm the fact that outbursts of the "red prominences," or spouts of hydrogen gas on the sun, follow the same law as the spots.

Periods of Maxima of			Periods of Minima of		
Sun-spots.	Amplitude of Diurnal Variation.	Aurora Borealis.	Sun-spots.	Amplitude of Diurnal Variation.	Aurora Borealis.
1778	1777	1778	1784	1784	1784
1788·5	1787	1787·5	1798	1799·5	1798
1804	1803	1804·5	1810	—	1811
1816·5	1817·5	1818	1823	1823·5	1823
1829·5	1829	1830	1833·5	—	1834·5
1837	1838	1840	1843·5	1844	1843·5
1846·5	1848·5	1850·5	1856·5	1856	1856
1860	1858·5	1859·5	1867	1867	1867
1870	1870·5	1870·5			

Secchi proved the existence of the same kind of coincidence between the amplitude of the diurnal variation and sun-spots for a number of years (1859-1865).

Gordon, in his *Physical Treatise on Electricity and Magnetism*, cites the following fact:—"In 1859 a magnetic storm of unprecedented magnitude continued from August 28th to September 7th. Professor Balfour Stewart has pointed out that this was synchronous with the period of maximum activity of one of the largest sun-spots ever observed." A member of the Royal Society of London published in 1875 a memoir on the variation of the mean daily horizontal component of the earth's magnetism, in which he concludes that these variations are related to the three periods of 26, 29·5, and 27·3 days, which are the periods respectively of the rotation of the sun on its axis and the synodical and tropical revolutions of the moon.

We have now stated the various theories which have been proposed to explain the periodic variations and also the sudden disturbances of the magnetic needle. Each of them has its own merits, but we must remember that new series of results with the more perfect instruments of the present time which are used in magnetic observatories must lead us to a better knowledge of these phenomena. Until then we can only offer more or less probable conjectures on the causes which produce these phenomena that are of such interest in terrestrial physics.

§ 6.—*Distribution of Magnetism on the Surface of the Earth.*

ISOGONIC, ISOCLINIC, AND ISODYNAMIC LINES.

Let us suppose that the number of stations, where the magnetic elements can be observed with great accuracy, are many and are spread all over the earth. At these let all the changes be noted which these elements undergo as we pass from one place to another. Suppose that, after a whole year of observations, we had calculated and reduced all the hourly, daily, and monthly mean values, the first result would be to give us, for that year, for the whole globe and for every point of its surface, the whole of the values of declination, dip, and intensity.

This state of things, this distribution of magnetism on our planet would be special, true only of the date at which the observations were made; but it is clear that in the course of years and centuries all the causes that we have discussed above come in to alter the value of the elements, so that our chart of magnetic distribution would be continually changing. The study of these changes is a very complicated matter. But we may simplify matters by omitting the hourly, daily, and monthly, changes, and confining our attention exclusively to the secular variations which go on with exceeding slowness, giving us time to take a bird's-eye view as it were of the magnetic state of the whole earth. By means of a series of lines which we shall presently define, we may make a geographical representation of the present state of the magnetism of the earth. This will render our study much easier and will obviate the use of the numerous tables compiled from observations.

There are two points on the surface of the earth where the magnetic needle points in a vertical direction, or, what is the same thing, where there is no horizontal component of the magnetic force. These places are called the *magnetic poles*. Although the needle stands vertical at these places the total intensity is not necessarily greatest at these points.

These two places are situated one in either hemisphere, but not at equal distances from the geographical poles. Humboldt thus describes the history of their discovery:—"It is due to the bravery and scientific keenness of one single navigator that we know the exact position of these poles. Sir James Clark Ross determined the position of the north magnetic pole during the second expedition of his uncle, Sir John Ross, in 1829 to 1833. The south magnetic pole he determined during his own expedition to the antarctic regions in 1839 to 1843.

"The north magnetic pole is situated about latitude 70° 5′ and 99° 5′ west longitude; being about five degrees more distant from the north geographical pole than the south magnetic pole is from the south geographical pole. The south magnetic pole is situated about latitude 75° 5′ and 151° 48′ east longitude. The longitudinal distance between the poles is 109°. The North Pole is situated in the Isle of Boothia Felix, near to the part of the American Continent called by Captain Parry, North Somerset.

It is situated a short distance from the west coast of the isle not far from Cape Adelaide, which is between King William's Sea and Victoria Strait. The south magnetic pole has not been directly reached as the North Pole has. On February 17th, 1841, the *Erebus* was in latitude 76° 12′ south and 161° 40′ east longitude. The dip was then only 88° 40′, so that it was concluded that they were not more than 160 nautical miles from the south magnetic pole. A great many observations of declination made with extreme care to determine the intersection of the magnetic meridians lead to the supposition that the south magnetic pole is situated in the great Antarctic polar Continent South Victoria Land, to the west of the Albert Mountains, which include the active volcano Erebus, which is about 11,000 feet high."

If a dipping needle be moved from one of the magnetic poles towards the equator the dip is found to decrease from 90° to zero, or the needle is horizontal. Let this be done in a great many directions over the earth. If those points where there is no dip be now joined, we shall have a line passing round the earth which will, however, be found not to correspond with the geographical equator. This line, however, is called the *magnetic equator*.

Just as we found the magnetic poles not to correspond with the geographical poles, so we have found the magnetic equator not to correspond with the geographical equator, but it cuts it in four points, one of them in the Pacific Ocean about 179° east longitude, and another near St. Thomas' Isle, off the west coast of Africa, about 7° or 8° east longitude.

The greater part of the magnetic equator lies in the northern hemisphere; its greatest distance from the equator being 15.° It crosses the Gulf of Aden and the Indian Ocean, the southern part of India and the Bay of Bengal, cuts through the Malacca Peninsula, passing north of Borneo and New Guinea, then turns to the south a little to the east of the Gilbert Isles, and to the south of the Fiji Islands. At this point it enters the southern hemisphere but is never far from the equator, passing north of the Marquisate Isles until it crosses South America, gradually getting more southerly between 7° and 15°. After leaving the coast of Brazil it again turns northward, across the Atlantic, and reaches the point from which we started in the Gulf of Guinea.

From the magnetic poles to the magnetic equator the dip varies from 90° to 0°, decreasing with the latitude, but the decrease is not regular. Lines can, however, be drawn round the globe through all the places having the same dip in the two hemispheres. By this means we can get a series of lines on a chart, showing at a glance the dip in various parts, these lines are called *isoclinic lines* or lines of equal dip. They are shown in Plate II. for every 10°. It will be at once observed that these lines follow in general the curves of the magnetic equator.

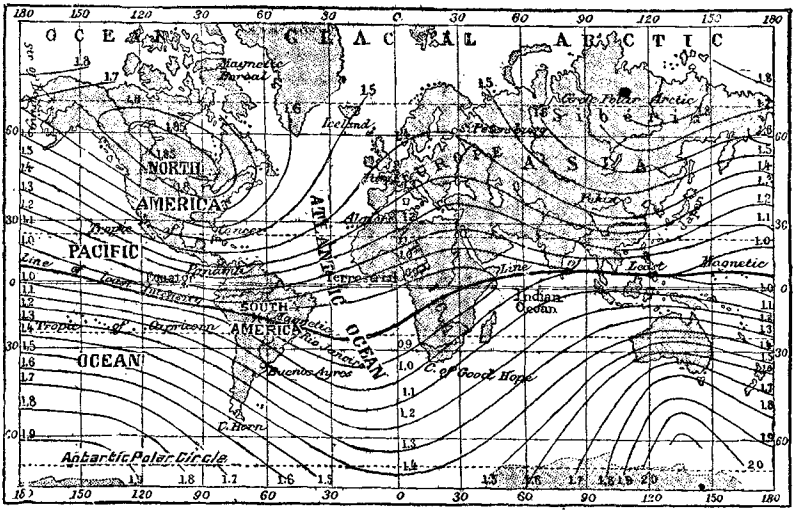

FIG. 59.—Isodynamic lines.

Applying the same mode of representation we can find a series of lines, the local variations in declination and in intensity. Those lines which connect points of equal magnetic intensity are called *isodynamic lines*. A third series of lines connecting points of equal declination are called *isogonic lines*.

Let us now examine these two systems of lines.

It has already been noticed that the intensity increases with the latitude, therefore the line of minimum intensity will be near the equator, but will not necessarily coincide with it, just as the maximum intensity is not necessarily at the poles. Be it observed that the isodynamic lines are more irregular than the isoclinic.

"When we follow attentively," says Humboldt, "the direction of the isodynamic lines, as they envelope one another, and as we pass from the exterior lines which are those of feeble forces, to the interior lines which are those of the stronger forces, we notice in each hemisphere, at very unequal distances from the geographical poles and from the magnetic poles, two points or foci, one of maximum intensity, and the other of minimum intensity. Of these four centres (which might be called poles of intensity) the strongest, the American centre, is in the northern hemisphere in latitude 52° 19′ and 94° 20′ west longitude, the weakest, the Siberian centre, is in latitude 70° and 114° 40′ east longitude, or perhaps some degrees further west."

The first centre, inclosed in an oval of isodynamic lines, is to the west of Lake Superior, between the extreme south of Hudson's Bay and Lake Winnipeg, as is shown on the magnetic chart (Plate II.).

The two points of maximum intensity in the southern hemisphere are not so accurately known; according to the observations of Sir James Ross and the researches of Sabine, one should be in latitude 64° and 135° east longitude, near Adelaland; the other about latitude 60° and 127° west longitude (Plate II., and Fig. 59).

Amongst the lines of equal declination the most important to be known are those where the declination is zero, in other words, where the magnetic meridian coincides with the geographical. These are the lines of no declination, or *agonic lines.* They constitute three systems. The first, which we may call the Australio-Caspian, starts from Adelaland, about 130° east longitude, crosses Southern Australia, runs across Borneo, where it cuts the equator, then turns sharp round to the west, crossing Ceylon and the tip of Hindustan. Then it comes back across the Indian Ocean and the Persian Gulf; from thence, still northward, through Kazan to Archangel and across the Arctic Ocean some degrees west of Nova Zembla. The second agonic line is about 100° west of the former, and is somewhat parallel to it, but not so markedly bent. It joins the two magnetic poles crossing both Americas, South America between Rio de Janeiro and the mouth of the Amazon, and North America from Carolina through the middle of Hudson's Bay. The third system is a closed, oval curve, inclosing concentric isogonic curves in Eastern Asia. The long axis of this ellipse lies almost exactly along the meridian

PLATE II.—CHART OF THE GLOBE, ON MERCATOR'S PROJECTION.

Showing the systems of Lines of Equal Declination or Isogonic Lines, and the Lines of Equal Dip, or Isoclinic Lines. The numbers marked at the margin indicate the degrees of dip of the magnetic needle along the various isoclinic lines. The horizontal straight line is the geographical equator.

135° east, and the short axis is nearly parallel with 50° north latitude. The northern half of the curve from N.E. to S.W. is in the Chinese Empire, from Pekin to the northern boundary and from there through Siberia to Kamtschatka. The southern half of the curve lies in the Pacific Ocean, and incloses the Japanese Archipelago.

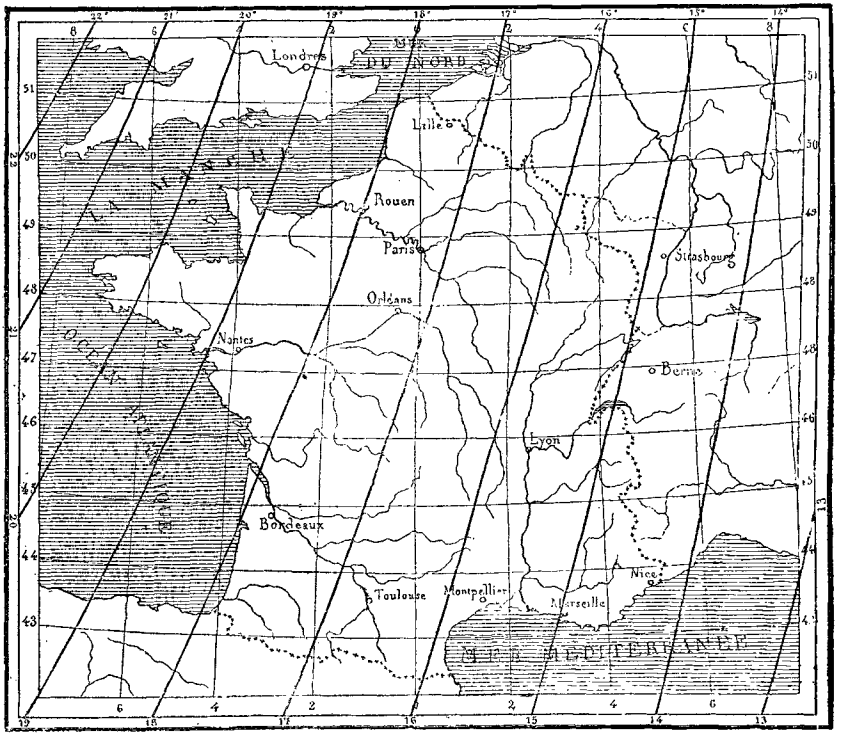

FIG. 60.—Chart of isogonic lines in France for January 1st, 1879.

Between the first two systems of no declination throughout Europe and Africa and two parts of the American continent, the declination is westerly. Isogonic lines divide themselves into two parts: those which lie between the two parallel agonic lines, some of them being very nearly parallel; the others of them which lie on either side of the equator being concave towards the poles.

In the remaining portion of the earth which contains Asia, the greater part of Oceania and America, the declination is easterly,

and the isogonic lines are curved in a very irregular manner; also in the space inclosed by the third system of no declination the declination is easterly. Nearly opposite to this system of lines (180° distant) there is another group of closed concentric isogonic lines lying on both the magnetic and geographical equators, and with its long axis parallel to the geographical equator.

When all these systems of lines, isoclinic, isogonic, and isodynamic, are drawn on a globe or chart, we can then see at a glance the distribution of magnetism over the face of the earth, for they show the direction and intensity of the force which acts on the magnetic needle. But it is evident that this distribution is only true for the time when the observations were made, as all the elements have secular, annual, and diurnal variations. Thus it comes about that the magnetic curves are slowly shifting in the course of time, as well as oscillating about a mean position with all the yearly, daily, and hourly variations.[1] Added to all this, we must not forget the sudden disturbances due to magnetic storms.

When the phenomena of terrestrial magnetism are looked at from this standpoint one can only compare the earth to a living body whose round of existence is being constantly affected by unknown causes. Whether it be the variation in the sun's heat, or the magnetism of the sun, or the influence of strange bodies, such as showers of cosmic meteors, that produce the irregular perturbations, we yet know not. One is also struck by the analogy that the geographical divisions bear to the magnetic; the isogonic lines being the meridians and the isoclinic the parallels of latitude, the great difference being that the latter are so irregular. This analogy might be false, if, as in certain charts, Duperrey's for instance, the magnetic meridians and parallels were drawn, and not the isogonics and isoclinics.

The following is the definition given of a true magnetic meridian by Duperrey:—It is a line obtained by carrying a magnetic needle from some point on the magnetic equator and always going in the

[1] For example, if we wished to compare the chart of isogonic lines of France shown in Fig. 60 for January 1st, 1879, with that for January 1875, the isogonic lines must be transplanted slightly to the west, about 25′, and parallel to themselves. In 1875 the declination at Paris was 17° 21′; in 1879 it was no more than 16° 56′; it had then decreased about 25′. This change is the effect of secular variation, and is almost the same for any points all over France.

direction that it points. Thus defined, the true magnetic meridian which passes through a given place is a tortuous curve; whilst the magnetic meridian, as ordinarily understood, being the intersection of the vertical plane containing the needle with the plane of the

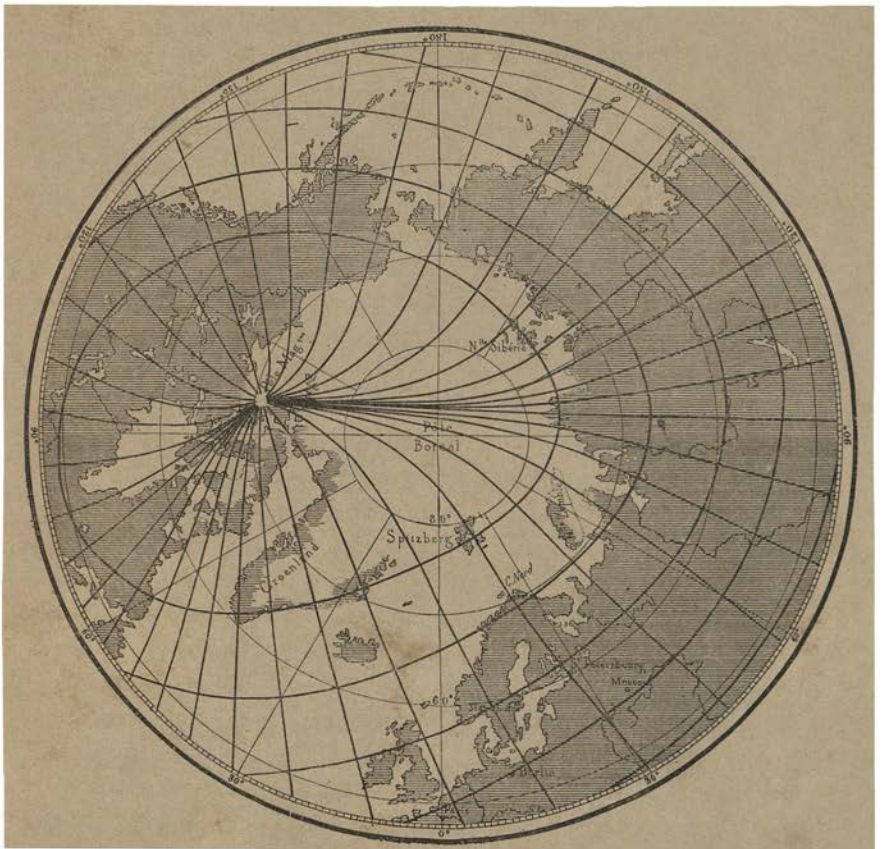

FIG 61.—Chart of northern regions, showing meridians and magnetic parallels, according to Duperrey.

horizon, is only a great circle. The magnetic parallels of Duperrey are curves drawn at right angles to the true meridians at any given point. These parallels must not be confounded with either the isoclinic or the isodynamic lines.

CHAPTER V.

TERRESTRIAL MAGNETISM.—POLAR AURORAS.

§ 1.—*Aurora Borealis and Australis; Description of Auroral Phenomena.*

AT rare intervals in the tropical and temperate regions, but more frequently in the polar areas, luminous phenomena of a curious character are seen in the sky at night. These appearances, known as *auroras*, are intimately associated with the magnetism of the earth. Particularly in the northern hemisphere have these beautiful illuminations been observed, and for that reason they are called *northern lights* or *aurora borealis*. Similar appearances are seen in the extreme southern latitudes. And according to certain recent authorities the displays of aurora australis are usually simultaneous with those of the aurora borealis.

In our climate auroras are, as just remarked, rarely seen, or, at least, their light is only occasionally bright enough to be distinguished from twilight. It is probable that we only see distinctly those auroras that are most brilliant and extensive. Perhaps more careful observations made in the temperate zone would prove a much greater number of appearances of the aurora if they could be compared with simultaneous observations made at stations in the arctic zone. As was remarked by a very able meteorologist, Charles Martins, the colours of the aurora are like those of twilight, so that a careless observer could easily confuse them with the ruddy tints which are sometimes seen on the north-western horizon for some long time after sunset. Sometimes they may be mistaken for the glow from a large fire. This, indeed, occurred at the commencement of the aurora on October 24th, 1870, during the siege of Paris. The red glow

was at first taken for an immense conflagration, which was not surprising at such a time. This idea, however, was soon put to flight as the phenomenon began to expand and vary itself. The following is an authentic account of the auroras of that night and of the night following:—

On Monday, October 24th, about six o'clock in the evening, a ruddy glow rose from the north-west horizon. Little by little the glow spread, rising in the form of an immense arch, covering all the northern part of the sky from east to west. Suddenly some brighter streamers of a pale red colour furrowing across the darkest depths of the sky removed all doubt as to the nature of the phenomena; it was a magnificent aurora.

During the day the sky had been overcast with clouds brought up by a strong west wind, but towards evening it had cleared, and when the aurora began the stars were shining almost from one end of the sky to the other. The luminous arch continued to increase in brilliancy, and to expand until about eight o'clock, when it reached and crossed the zenith. The red tint was very vivid above and in the easterly and westerly horizons. In the north the colour was less marked, and beneath the luminous arch lay the dark segment often seen in auroras.

Except the streamers, which here and there at irregular intervals crossed the base of the arch, and which were of a pale red or pale orange tint, the whole aurora was of a uniform ruddy colour. This colour, however, varied somewhat in tone, it was sometimes rose red, at other times blood red, and, again, of a deep crimson; but all through it was perfectly transparent, allowing even stars of the third and fourth magnitudes to be seen distinctly. The Great and Little Bears, Cassiopeïa, Aldebaran, and the Pleiades, were all distinctly visible. At the moment when the arc reached the zenith the whole of its outer edge was bordered with a milk-white tint, resembling in colour the Milky Way, but much more regular and uniform. Then the display began to fade, though it was still visible after eleven o'clock. The greatest brilliancy was between eight and half-past.

The following evening, Tuesday, October 25th, is memorable for another aurora; we will only describe those points in which this one differed from that of the preceding night:—

The luminous arch extended across the sky from east to west, but passed the zenith extending into the southern skies. In the north, about 30° degrees from the horizon, was seen a small red patch of the same tint as the arch. Between the north and the west was a region of clear sky showing a faint greenish-white opalescence in strange contrast to the surrounding regions. As in the preceding aurora, many streamers of a reddish hue shot up from time to time, but apparently not converging in any particular direction. One of these streamers, of a long, straight form and broad at its middle, was remarkable for the persistence of its position ; it might have been taken for a cloud.

Between seven and eight o'clock in the evening the streamers presented a very curious appearance worthy of being recorded. To the east of the constellations of Andromeda and Pegasus, at a point near the two second magnitude stars, μ and λ, there suddenly appeared two and then three small rose-white patches glowing like little luminous clouds or nebulæ. These, while maintaining their general form, grew little by little in length, converging in three lines towards the point in question. Other rays of all sizes appeared one after the other in all directions, all of them converging to the same point in the heavens, giving the phenomena the appearance of a glory round the head of a saint.

We also saw at the same time two brilliant shooting stars, but we could not exactly determine either their radiant point or their direction.

Auroras as brilliant as those we have just described are very rare in our climate. Leaving the temperate zone to go into the polar regions, we find that auroras are both more frequent and more brilliant. One who has seen them, M. Martins, thus speaks— "The phenomena [of the aurora in arctic regions] are seen with a splendour and magnificence not comparable with anything else. Brilliant and varied as a display of fireworks, the sight changes every moment. There is not time for the painter to catch the form or tint of their changing lights: even the poet fails to describe them. Never are there two auroras alike: their variety is infinite."

Before giving a full and concise description of the various and complex phenomena of auroras, let us once more quote from

PLATE III.—AURORA BOREALIS IN THE SOUTH, SEEN AT BOSSEKOP; OF HOOK SHAPE.

M. Martins a description of one of the sights seen by him in his travels in Spitzbergen and Lapland. "Sometimes auroras," he says, "are simple diffused glows or luminous expanses; sometimes they are shimmering streaks of brilliant whiteness drawn across the sky from the horizon as if an invisible pencil were at work on the vault of heaven. Sometimes it stops: the rays fail to reach the zenith, but the aurora continues at some other point, a sheaf of rays advances, spreads out like a fan, then fades and dies away. At another time long golden draperies will hang above the spectator's head, waving to and fro their thousand folds as if swayed by the wind. They seem to be not far above the earth: and one is astonished that the rustling of their folds is not heard. Most frequently a luminous arch appears towards the north, separated from the horizon by a dark segment, the sombre hue of which is in striking contrast with the arch. Glowing with white on red, it shoots upward luminous rays, spreads, parts asunder, ranges itself fan-wise, filling the whole northern sky, mounting little by little to the zenith, where the rays uniting form a corona, which in its turn throws out shining streamers in all directions. Then the sky seems one vast dome of fire, with interplay of colours, blue, green, yellow, red and white mingled in the quivering rays. This brilliant sight does not last long. The corona ceases to throw out its luminous jets, and gradually fades. A diffused glow fills the sky. Here and there a few luminous patches like light clouds part and meet with indescribable activity, in strange palpitation. Soon comes their turn to fade. Confusion and destruction reign: it seems like the death-agony of the aurora. The stars again begin to shine with a new brightness, and the solemn darkness of the long arctic night again reigns supreme over the frozen solitudes of land and sea."

§ 2.—*Historical Sketch of the Aurora Borealis.*

It is not easy to distinguish, among the descriptions of the varied phenomena of all kinds that have been left us by the ancients under the name of "luminous meteors," which of them relate strictly to the aurora. Rainbows, mock suns, shooting stars, phosphorescent

mists, and even comets were included along with genuine auroras under that name. From Aristotle to Pliny the confusion due to the ignorance of the subject of cosmic and atmospheric phenomena caused comets, shooting stars, the electric glow of storms, zodiacal light, and auroras to be all classed in one category, although from various authors they received as many as twenty different names. Is not Aristotle speaking of an aurora, when he compares the phenomena that he is describing, to a blaze mixed with smoke, to the light of a lamp which is going out, to the glow of a country when the stubble is being burned? Is it not the dark segment seen below the arch of an aurora which the same author had seen when he says: "The *chasm* (chasma), the opening which is seen in that part of the sky, because of the interruption of the light that strikes on all things round about, and because of the dark blue tint in which it is coloured, is so-called because it appears to us to have a sort of depth" (*Meteors*).

Here is Seneca's description taken from his *Quæstiones Naturales*, Lib. I. This somewhat resembles Aristotle's, but is more precise, and can only be taken to refer to auroras.

"At times there are," he says, "fire-glows, sometimes fixed and persistent, sometimes flitting. Of these many sorts may be distinguished. There are *Bothynoë*, when, as within a surrounding corona, the fiery recess of the sky is like to a cave dug out of space. There are *Pithitae* when the expanse of the vast and rounded fire, similar to a tub, is either carried about or glows in one spot. There are *Chasmata*, when a certain portion of the sky opens, and gaping, displays the flame as in a porch. The colours also of all these are many. Certain of them are of the brightest red, some of a flitting and light flame-colour, some of a white light, others shining, some steadily and yellow without eruptions or rays."

Further on Seneca says: "Amongst these we may notice, what we so frequently read of in history, the sky is seen to burn, the glow of which is occasionally so high that it may be seen even amongst the stars, and then again slipping down so near to the earth as to appear like a fire in the distance."

This is the distinctive character of the auroras observed in our climate, which are however very often reduced to bright lights on

the horizon, and only as an exception rises to the zenith, as we mentioned in the two occurrences of the 24th and 25th of October, 1870. Formerly they were confounded with incendiary fires, and are so still sometimes. "Under Tiberius Cæsar, the cohorts ran to the help of the colony of Ostia, which was thought to be on fire, the sky glowing through a great part of the night, shining dimly like a vast and smoking fire."

We shall not enter further into the details of the history of auroras in ancient times or the middle ages, for the records left of their appearances are often mixed with fables and fantastic descriptions which the superstitious credulity of observers caused them to believe, no doubt in good faith, but which are devoid of scientific interest.[1]

Mairan, in his *Traité de l'Aurore-boréale* cites a number of similar instances.

It is not till the first years of the seventeenth century, in the year 1621, that we find the first scientific mention of an aurora: it is the one seen and described by Gassendi[2] the historian.

Already in 1615, La Mothe le Vayer, in a letter entitled *De la Crédulité*, begins to protest against the superstitious interpretations of these celestial phenomena. He quotes a contemporary who pretended to have observed, on the 26th of October, 1615, "men of fire who fought in the sky with lances, and who, by this frightful spectacle prognosticated the fury of the wars which followed;" and he adds: "I, however, was in the city as well as he, and after having

[1] Here are the terms in which Cornelius Gemma speaks of two auroras, one of which appeared in February, the other in September, 1575: "The first," he says, "appeared at about nine o'clock in the evening of February 13th, the other soon after sunset, at about seven, the eve of St. Michael, September 28th. The first, by the order, the nature and variety of its forms, puts before our eyes a faithful picture of the calamities, vicissitudes, and all the strokes of fortune to which Flanders was soon exposed. . . . . What did those two great wonderful arches mean? One towards the north seemed to come from the dark gulf whence came forth other arches, and a great extent of light; the other, declining a little towards the south, representing Iris, by the different colours with which it was painted, extended from east to west, passing through the belt of Orion. The most northerly arch divided near Orion's belt, and there issued a great quantity of rays, lances and inflamed swords; they disappeared with incredible rapidity: it was the image of a bloody combat."

[2] We owe to Gassendi the modern name of the phenomenon, "aurora borealis." Cassini at the end of the seventeenth century employed the name of "northern lights."

carefully contemplated till eleven at night the phenomenon he mentions, I declare that I saw nothing of what he reports, but only an appearance in the sky, common enough, in the form of canopies, which appeared and flamed up from time to time, as happens often with such meteors. No end of people still living can testify as to what I say."

Cool and impartial observation was substituted by degrees for the illusions of credulity. Science took possession of the domain of the supernatural. From that time, the attention of the learned world was fixed on these phenomena, and precise observations became multiplied. Cassini, who carefully collected all observations relative to atmospheric lights in order to distinguish those that belonged to the zodiacal light, cites in 1687 some apparitions of a very white light, which appeared at night near the northern horizon, and he calls it "the northern light:" it was, without a doubt, the aurora borealis. He quotes on this subject an account by an author mentioned by Gassendi, wherein there is a clear description of the phenomenon of the aurora as seen in polar regions. The following is this passage: "The summer in Greenland is always beautiful day and night—if you can call night the perpetual twilight which occupies in summer all the night-time. As the days in winter are very short there, the nights are very long, and nature produces a marvel, which I should not dare to describe, if the Icelandic chronicle had not written of it as a miracle. There rises at nightfall in Greenland, when the moon is new, or on the point to become so, a light which lightens the whole country, as if the moon were full; and the darker the night, the more this light shines. It is generally in the north, and for that reason is called the northern light: it looks like flying fire, and extends into the air like a high, long palisade. It passes from one place to another, and leaves smoke at the places which it quits; it lasts all night, and vanishes at the rising sun." This author adds that this northern light is clearly seen in Iceland and Norway when the sky is clear and there are no clouds; and that it "enlightens not only people of this arctic world, but it extends also to our climates;" and he thinks that "this light is the same that was observed by M. Gassendi on the 13th September, 1621, and is described in the life of M. de Pereisec, and elsewhere called the *aurora borealis*" (Cassini, *Découverte de la Lumière céleste qui paroist dans le Zodiaque*).

In the eighteenth century auroras were studied by a great many observers among whom were Roemer, Liebknecht, Halley, Maraldi, de Plantade, Godin and Musschenbroeck. Theoretical explanations were sketched out, and Mairan wrote his *Traité de l'Aurore-boréale*,[1] which was very successful.

We shall have occasion to mention the theories propounded at that time. But it must be remembered that till recent times the phenomenon was rarely studied in the region where it presents itself in all its brilliancy, with all its various aspects, and with a frequency which had never been suspected. To those scientific men who have in the right place and methodically, made observations and studies of auroras, we must now pass for the final descriptions before we attempt to expound the theory which links these interesting phenomena to those of terrestrial magnetism.

§ 3.—*Physical Characters of the Aurora Borealis. Dark Segment; Height and Width; Parallax.*

One of the most remarkable series of observations of the aurora borealis in the arctic polar regions is due to those who from 1838 to 1840, went on a scientific expedition on board the corvette *La Recherche*, to Scandinavia, Lapland, Spitzbergen, and the Faroe Isles.

The study of terrestrial magnetism had been entrusted to the French philosophers Bravais and Lottin, and to the two Swedes Lilliehöök and Siljeström. Bravais summed up in one chapter the

[1] Mairan, in his book, gives a table of the appearances then known of auroras, from the year 583 to the year 1751. He finds 1441, 150 of which only were anterior to 1621; they were scattered over the months of the year—

January, February, March	456
April, May, June	191
July, August, September	278
October, November, December	516
Total	1,441

The total of the auroras which appeared in the winter six months is 972, that of the summer only 469. Thus they appear to have been about twice as frequent in winter as in summer.

results of observations on polar auroras. We will give an analysis of them, taken partly from the pen of Élie de Beaumont, completing it by some data taken from the memoir of Bravais itself; this memoir being, in the opinion of competent judges, the clearest that has been written on this subject.

"When the first doubtful gleams of an aurora began to spread in the sky, there was perceived on the horizon, a little to the west of north, a dark segment, which, according to the probable conjectures of M. Bravais, was only the compact mass of fog with which the temperate waters of the polar sea are constantly covered. Above this dark segment there soon appeared lights, like those coming from a

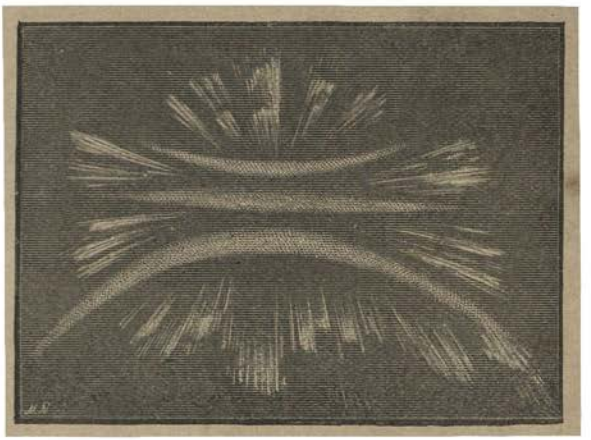

FIG. 62.—Aurora of December 10th, 1838, observed at Bossekop; arches and streamers forming a dome.

fire, resulting perhaps merely from the lights of the still distant aurora reflected on the lower vapours. Some time after a luminous arch appeared above the dark segment. Its two ends rested on the horizon, and its culminating point, which divided it into two equal and symmetrical parts, was situated near the magnetic meridian. Generally it fell a little to the west[1] of this meridian, from which it became gradually more distant as it got further from the northern edge of the horizon, particularly when passing the zenith it approached

[1] According to Bravais, the deviation was about 11° towards the west for the arches situated at the zenith; more for the arches at the south. Argelander confirmed this deviation at Abo.

the meridional horizon, from which it is distant, in certain cases, a few degrees only.[1]

"Sometimes several different arches show themselves at the same time, very often two, more rarely three; nine have been counted at

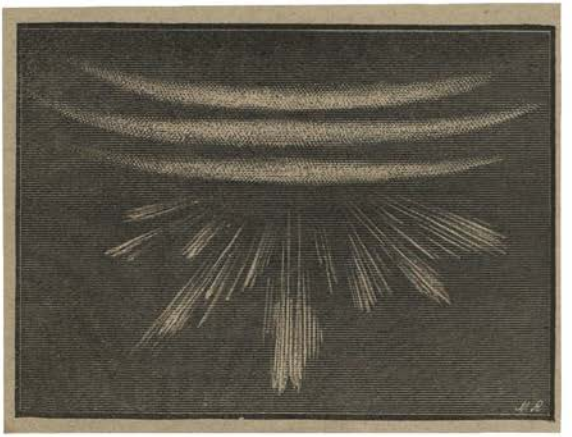

FIG. 63.—Aurora observed October 17th, 1838, at Bossekop; corona and inverted arches.

one time. Their width, which averages seven or eight degrees, sometimes exceeds twenty-five degrees, particularly in the highest part, where they pass near the zenith. By the combination of measure-

[1] In describing the dark segment Bravais asks this series of questions, all of which have not yet been answered: "Does this dark segment always accompany the aurora? When it shows itself, is it always followed by aurora? What is its nature? Is it the simple effect of contrast? May it be likened to an ordinary cloud, or must we admit the existence of a special matter which causes it?" He cites examples of auroras, the appearances of which have not been preceded by this dark segment; during six weeks, remarkable for the serenity of the sky, this segment ceased from appearing completely, though the same period was rich in auroras. During a whole winter passed at Talvig, Professor Keilhau expressly, remarked that he perceived no dark segment. Every time that Bravais observed this segment it was situated in the magnetic meridian, in the direction of north or north-west, sometimes west. Now, he remarks it is precisely in that direction that the icy sea is, at only some scores of miles distance. "An immense layer of fog," he says, "covers it during great part of the winter, and our meteorological observations indicate that the atmosphere is habitually foggy on that side, both by day and night. This fog, driven by wind, comes often towards us, reaches our zenith, and resolves itself into flaky snow."

The different circumstances of the phenomenon seem to be well explained by this hypothesis. Nevertheless, Bravais cites some cases, though few in number where luminous arches or auroral sheets appeared inside this dark segment.

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ments, this last observation leads to the belief that the arches of the aurora are flattened parallel to the surface of the earth; and it suggested to Bravais one means of furnishing the measure of the height which they are above the ground.[1]

"For a long time past philosophers have been occupied with this height, and it was reasonably thought that it could be calculated by the parallax resulting from two observations of the same arch, made simultaneously by two observers placed at a known distance. In order to use this means of determination, Bravais passed thirteen days, from the 9th to the 22nd of January, 1838, at Jupvig, a place situated at 15 kilometres north of Bossekop, to follow out there the auroras, which his fellow labourers observed at the same time from the usual place."

The forms of a great many arches, particularly those that were the most regular, were recorded with great care by the commission, and Bravais, in discussing them, by means of elegant geometric constructions, and trigonometrical formulas, very skilfully reduced to great simplicity, was able to show that all these arches may be considered, in conformity with the hypothesis of Hansteen of Christiania, as circular rings seen in perspective having their common centre on a terrestrial radius drawn in the direction of the magnetic pole, and their plane perpendicular to this radius.

"His formulæ have given him, in each case, the elevation of the ring from the surface of the earth; and the average of this measure, combined with the two others already mentioned, leads him to conclude that auroral arches are situated at an elevation of 80 or 150 miles, in that upper region of the air where the shooting stars, and meteors become incandescent, that is, towards the extreme limits of the terrestrial atmosphere, the altitude of which was for a long time considered of less extent."

[1] From the discussion of a great number of measures of auroral arches, Bravais deduced the average heights and widths to be the following, the heights being reckoned above the northern horizon, and going beyond 90° for the southern arches:—

	Height.	Amplitude.	Width.
Northern arches ...	44°2 ...	152°4 ...	7°
Zenith „ ...	90°0 ...	175°4 ...	25°
Southern „ ...	123°0 ...	184°9 ...	7°8

The width of 25° is deduced from arches situated from one side or other of the zenith at 30° distance north or south.

Before Bravais, many observers, physicists and astronomers, had attempted to determine the geometric elements of polar auroras, particularly the height of the arches above the surface of the earth. But these attempts had given very contradictory results. Whilst Christie and Hansteen deducted from their simultaneous observations (the aurora of January 7th, 1831) that the heights varied from 37 to 192 kilometres (22 to 120 miles), others, Thienemann, Wrangel, Struve, and Farquarson thought that at the greatest height, the arch did not go beyond the regions of clouds. But their opinion seemed rather to be based upon certain luminous effects observed in such or such particular aurora, than on positive measurements. Bravais, whilst recognising the difficulty of making an exact observation on the position of such a hazy object as the edge of an auroral arch, remarks that the results which he obtained are rendered highly probable from the fact that the average height of the arches, from 100 to 150, or 200 kilometres (62 to 93 or 125 miles), is of the same order of magnitude "as that deduced from the variation of the amplitudes of the arches during their apparent rotation round the perpendicular of the magnetic meridian, and the comparison of the width of the zenithal bands at their summits and at their bases."

Various appearances have led to the idea of auroras being situated only at a small distance. Bravais discussed these appearances, and easily showed that they are far from being conclusive.

He says: "The illusion that leads us to judge of auroras as being near, is sometimes due simply to the smoky appearance of the light, principally when their movement looks like puffs of vapour which escape from a locomotive; no one can attach any value to such an indication." Sometimes the aurora seems to be situated between a mountain and the observer; the bases of its streamers seem to prolong themselves below the summit. Such an appearance presented itself to Bravais, who explains it by the reflection of the light on the crystallized snow which covered the mountain.

A very common opinion, not only among the inhabitants of arctic regions, but also with some physicists, attributes to auroras a peculiar rustling noise, which the observers at Bossekop were not able to hear, in spite of the continued attention they gave to following the different phases of a great many auroras.

Bravais thought that those who believed they heard this noise

were deceived by several causes. "Such as," he says, "the whistling of the wind, the whirling of the snow, the distant murmur of the sea, the cracking of the snow, which congeals after having begun to melt, &c." On the same subject we may mention Siljeström, who agrees with Bravais.

FIG. 64.—Aurora observed in February, 1874 (expedition of Tegetthoff); smoke-like appearance of the auroral light.

"I have tried," says Siljeström, "to obtain from the inhabitants of Finmark some indications of the aspects of auroras, and, above all, on the alleged noise.

"Most of those to whom I have spoken assure me that they have truly heard the aurora, on occasions when this phenomena has been unusually brilliant. Many told me also that they had seen the aurora

descend to the ground and surround them completely with its light; this had happened when they crossed in winter over the great mountainous plateau which separates Finmark from Lapland. The Lapps generally believe that a certain noise is heard with the aurora, and they compare it to what is produced in the leg-joints of the reindeer during their walk, and which resembles the crackling noise of electric sparks.

"I think that all these assertions may depend on an illusion of the senses. And first, as to the descent of the aurora on the ground, we must reflect on the deceptive effect of the reflection of light on an indefinite plain of snow, the sky being covered on all sides with strong auroral light.

"M. Thomas, an engineer of mines at Kaafiord, declared he had seen the aurora between him and a mountain which he pointed out to me, but he had heard no noise. As to this alleged noise of the aurora, I cannot deny it, but there is at least reason to suspect that there is some illusion capable of easy explanation. In short, when one sees the whole sky covered with flames, as is the case in the most vivid auroras, when one watches these flickering lights, endowed with rapid movements, or the streamers forming for an instant and vanishing like rockets with amazing rapidity, and sparkling with vivid light, it seems to me very natural that the spectator should be led into error, so that, with all these appearances of fire, he should imagine that he hears the crackling of it, and applies to the sense of hearing what he has only learnt by sight. On the other hand, the possibility of a first illusion being granted, we know how easily an error is propagated by tradition, in spite of the witness of unprejudiced senses.

"Among those whom I questioned on this subject was an old man of seventy, to whom I owe many ideas on other questions relative to Finmark. This man, who was much occupied with agricultural experiments, and who had always observed with interest the state of the sky and the wind, had never heard a noise with the aurora. Accordingly the fact appears to me very doubtful."—*Voyages en Scandinavie, Laponie, &c.*

§ 4.—*Physical Characters of Auroræ Borealis: Brilliancy, Colours, Movements of the Arches and Streamers.*

From the geometrical appearances of auroras, and their probable distance from the earth, we pass to their physical aspect and their light.

The form of the auroral arches is often so singular and so irregular, that it defies description. Drawing only can give an idea of it. The Plates I., III., and IV., and Figs. 62 to 68, will supply this defect. Let us remember that, according to Bravais, one of the most singular and most constant forms of the auroral arch, is that which gives it the appearance of *undulating drapery*, and suggests the folds of a flag or the pennant of a ship of war, spread out horizontally and agitated by the wind. "It is not," he says, "a simple optical illusion which causes the observer to see in the arch undulating folds, some parts hollow and some in relief, though, in the greatest number of cases, he cannot put the matter to certain proof. These forms of festoons and drapery seldom show themselves, except in the arches formed of streamers placed close together; they are rare in the unstriated nebulous arches, and constitute one of the most characteristic and most striking traits of the aurora." Bravais also pointed out the hook-form (Plate III.) which the eastern extremity of the arch often assumes when it becomes curved upwards, to direct itself to the point of the horizon above its summit; more rarely the hook is seen at the western part of the auroral arch.

A curious phenomenon is that of the shifting of the arches, which, when once formed, do not invariably remain fixed in their original place, but can displace themselves, and are often transported in a direction parallel to themselves from the north to the south, or from the south to the north. "An arch which at first is first seen near the northern horizon may gradually lift itself, reach the zenith, descend towards the southern horizon, remain there some time stationary, and then retrace its steps. The feet of the arch almost stationary at the east or west of the compass appear then to turn round those points, as if round hinges."[1]

[1] In the abstract of his observations Bravais states that arches of the aurora have been seen to move sixty times from the north to the south, thirty-nine times from the south to the north. He finds there were twenty-five nights when the

PLATE IV.—AURORA BOREALIS OBSERVED AT NOULATO, ALASKA, ON DECEMBER 27, 1868, BY F. WHYMPER.

In the hooked arches we distinguish a second kind of movement from west to east or from east to west. Lastly, it also happens that while the height of the arch remains the same, its feet change places: the whole arch appears then to turn round vertically, either in the direction of the diurnal motion or in the opposite direction.

The speed of the movement of translation often reaches to 5° and even, though rarely, to 17° a minute. In the first case, allowing for the arch a vertical height of 200 kilometres in the atmosphere, the effective speed would be equal to 300 metres a second, supposing that to the apparent movement of the arch there corresponds a real transport of ponderable matter.

The light of the arches of the aurora is usually of a yellowish white, the lower edge is more clearly delimited than the upper one. This feature may be partly explained by the greater distance from the observer of one, than the other; but it is possible that the difference arises from the greater condensation of the auroral matter on the most northerly edge of the arch.

As for the light of the arches, Bravais compares it in the brightest instances to that of the stars of the first magnitude; but most often he compares it to stars of the second, third, or fourth magnitude.

Fig. 65 depicts a very strange occurrence which was observed at Bossekop in 1838, namely, the appearance at the same time of an aurora and of a lunar halo. Lilliehöök thus speaks of one most curious feature: "There is an intimate relation between the light of the halo and that of the aurora; for at the point where an auroral streamer intersects the halo, the latter is broader and its light more condensed.

"The most singular phenomenon that the arches of the aurora present is, without doubt, their tendency to break up into short rays, usually pointing in the direction of the width of the arch, and converging towards the magnetic zenith. Also, very often the arches appear to be formed of fibres crossing their edges, clearly cut at their extremities, following a regular curve, which forms the lower edge of the arch. The unstriated arches which have nebulous edges

first of these movements only were observed, eleven nights during which the inverse movement took place; and during seventeen nights the two movements in opposite directions were observed.

and are homogeneous in their luminosity, are not, perhaps, the most frequent: arches composed of streamers, or *radiated arches*, are very often seen." Between these two forms there are very many intermediate forms; frequently, also, a nebulous arch will resolve itself partially or totally into a radiated arch. In Figs. 62, 63, and 65, are examples of this partial decomposition.

The brilliancy of the streamers or rays, and of the luminous columns, which, according to Bravais, form the second type of auroral lights, is, like the brightness of the arches themselves, variable, but it is brighter in proportion to the surface.

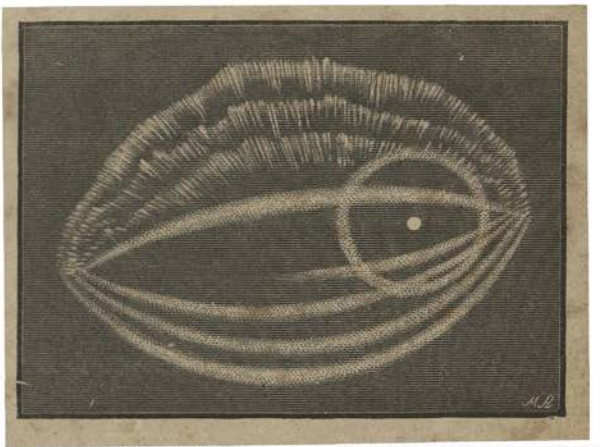

FIG. 65.—Aurora borealis and halo, observed at Bossekop, on November 2nd, 1838.

Nevertheless, stars are often visible through them, and if they disappear, it is because of the brightness of the field on which they are projected.

Streamers are subject to two movements: one in virtue of which the ray lengthens out towards the zenith or horizon; the other, which moves it in a parallel direction to the right or the left. These movements are sometimes very rapid. Bravais mentions a streamer which in twenty-seven seconds traversed over the sky an angular space of 90°. According to him, the lateral movement was not real; he thinks he may affirm that most often it is simply a play of light, due to the successive brightening of immoveable lines; he characterises it by the name of *undulatory movement*, or *undulatory appearance*.

The longitudinal, or vibratory movement, offers certain interesting peculiarities. If the ray, while remaining nearly in the same place, lengthens out rapidly towards the top or the bottom, it is said to *dart;* it plays, or *dances,* when it goes up and down alternately without its length changing much. "This," says Bravais, "is the most frequent movement, and one of those which best characterises auroras. These playing and dancing rays are the *capræ-saltantes* of ancient authors, the *marionnettes* of Newfoundland and Canada, the '*merry dancers*' of England."

Sometimes the auroral rays are disposed in great numbers so as to converge towards the same region of the sky, the central part of

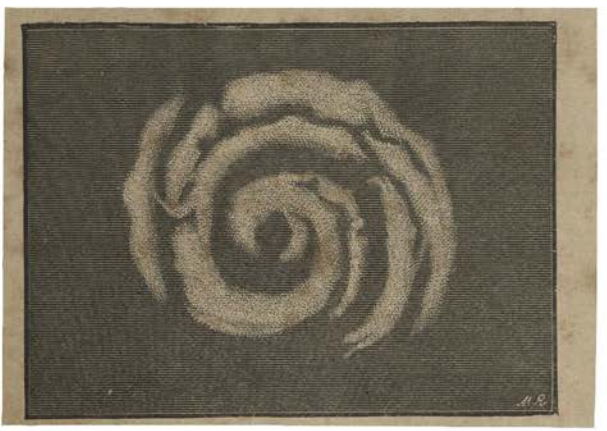

FIG. 66.—Aurora of September 28th, 1838, spiral form indicating a rotatory movement.

which remains dark. The whole has the appearance then of a rough kind of corona. Fig. 62 presents this aspect if you disregard the central band and the two arches on each side. This form is due to an easily-explained effect of perspective. "If the part of the terrestrial atmosphere," says Bravais, "situated above the plane of the observer is occupied by a great number of separate rays, all parallel to each other, and in the direction of the needle of inclination, there will be formed, according to the rules of linear perspective, a 'vanishing point' towards which all the rays will appear to converge, and which will be determined by the meeting of the celestial sphere with the visual line from the eye of the

observer parallel to the dipping needle; it is this vanishing point that we call the magnetic zenith."

The auroral coronæ are not always complete; sectors of great or small width may remain destitute of light. Sometimes they are very splendid; the rays composing them being extremely vivid. When they are in movement they change from their habitually yellowish tint to red and green. "At such a moment," Bravais says, "the corona offers the highest degree of splendour that an aurora can display." It is a remarkable circumstance that during

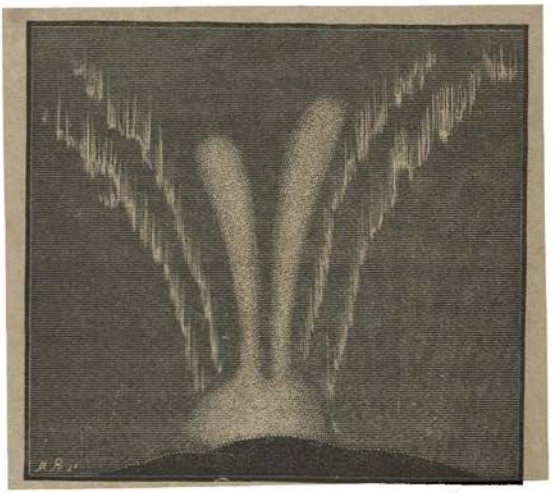

FIG. 67.—Aurora borealis of December 25; auroral bands.

the time that a brilliant corona is visible, the other lights of the aurora become pale, to become bright again after the disappearance of the corona. It then often happens that the streamers separate, going towards the north or the south, or both at one time; they become very pale, increase to a prodigious length, and form an immense luminous belt all round the horizon.

To complete our description of all the appearances which auroras take, we must notice the *patches* or *plates*, a kind of diffused light of an oval form, like cirrus clouds, also vague and nebulous lights, and *auroral vapours*, which spread over a considerable portion of the sky, covering it sometimes almost entirely; and lastly the *bands*, like

nebulous columns, of which Figs. 67 and 68 represent two singular cases. The lights in question, though of small intensity when they occur in the upper region of the sky, when they accumulate on the horizon, produce a light that is vivid enough to resemble a great fire. They undergo irregular movements, a kind of palpitation, which affects the whole, so that the auroral *lights* and *plates* obey the same alternations of ebb and flow in their light. They cover the sky at a late hour of the night; their appearance generally announces the near extinction of the aurora.

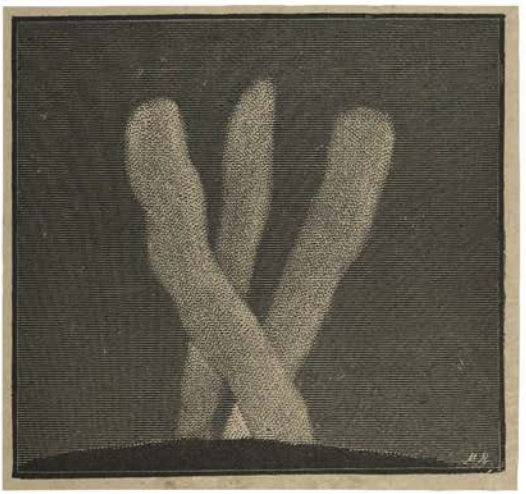

FIG. 68.—Aurora of January 3rd, 1839, observed at Bossekop.

Whatever may be the nature of the matter which composes the aurora, everything goes to show that it must be of great tenuity. The light of the stars is scarcely weakened by its passage through it. Besides, Argelander, in his astronomical observations at Abo, was not able to discover any trace of refraction produced by auroral light, and Bravais verified the exactness of this fact by determining the altitude of the pole star as seen through an aurora.

The illumination produced by the aurora is generally inferior in brightness to that of the full moon. "All that I was able to do," says Bravais, "by the light of the very brilliant corona of January

10th, has been to read, not without difficulty, some words in a type known in printing under the name of *small text*. This type is quite easily read by the light of the full moon." In no case has the intrinsic light of the arches or streamers of an aurora equalled that of lunar light.

We will conclude this description of the phenomena which auroras offer with a few words on their colour. This colour is generally white, but it turns sometimes to pale yellow or red. When the brilliancy becomes more intense, and the rapid movements already described take place, the rays become coloured, a brilliant yellow tint flows from their extremities to the centre, and, according to some observers, the extremities themselves become one red, the other green. The red of the aurora is tinged with violet, being more of a crimson than a scarlet, and the green is slightly bluish.

The light of the aurora borealis was not studied with the spectroscope by Bravais, because at the time when he made his numerous observations in Lapland the method of spectrum analysis was not known. But more recently it has been recognised that among the various rays that may be present in the spectrum of an aurora there is one always present; it is a green line, the wave-length of which, according to Angström, is 0·000557 millimetres. Respighi, Winlock, Clark, and others, who specially observed for this purpose the aurora of February 4th, 1872, all agreed that the line-ray thus indicated by Angström was visible at every point on the whole surface of the sky at which the spectroscope might be directed. The following is what Secchi says:—

"We thought we saw hydrogen lines, but we did not determine their position satisfactorily. We even saw portions of a continuous spectrum. At those instants when the phenomena was the most brilliant we saw many lines, and, in the green, one part of the auroral spectrum presented to us the channelled appearance which the spectrum of nitrogen possesses. We see then that the light of a Polar aurora is very variable." Zöllner attributed the principal line of the auroral spectrum to oxygen at a low temperature. Respighi confirmed the presence of the same line in the spectrum of the zodiacal light, which would be, according to him, a proof of a common origin. It appears equally certain that this line exists in the spectrum of the solar corona.

Having now described, in all their details, the phenomena of the aurora borealis, and before saying what hypotheses have been proposed to explain them, we must state what is known about the frequency of their occurrence.

According to the observations of Bravais, which embraced a little more than six months of the winter period (from September 19th, 1838, to April 8th, 1839), out of 201 days 151 auroras were visible. As in the fifty remaining nights the sky was mostly cloudy, he concludes that "nights without auroras are decidedly exceptional nights." Now, is this permanence of auroras indefinitely maintained in the Arctic regions? That is a question which that distinguished observer was not able to answer, though nothing in the statements received from the mouths of the inhabitants of Finmark authorised him to think that the auroras were more numerous in the winter of 1839 than during the preceding winters. Besides, he thinks that the aurora often exists in the day as well as in the night, so that "the auroras of two or more consecutive nights may have been only one phenomena, the duration of which was prolonged during many days and nights."

"This uninterrupted succession," he adds, "does not prevent the aurora from being subject to diurnal periods, at least relatively to some of its manifestations. Thus the appearances of arches, of rays or plates, the hour when the lights become coloured, or attain their greatest brilliance, undulate or palpitate, the hour of their disappearance, &c., all these are not a matter of chance. The diurnal period of the successive phases is very evident, and those of the magnetic perturbations which accompany them are not less so." It is generally towards ten or eleven o'clock in the evening that the phenomenon is in its greatest splendour.

Further examination of the observations proved to Bravais that the movements observed in the arches and the streamers cannot be attributed either to rotation or the translation of the earth, nor to the general movement which carries the solar system through space. The conclusion to be drawn from that is, that the aurora borealis is a terrestrial phenomenon, atmospheric in its origin, and not a cosmic phenomenon foreign to our globe.

The frequency of the aurora in regions near the pole has caused the remark to be made that its light appears to have

been given as a compensation to those countries disinherited of the sun. To that must be added the light of the moon, which being full when opposite the sun remains then nearly always on the horizon.

"The double light of the moon, and the aurora in polar regions, greatly diminishes," says Élie de Beaumont, "the darkness of the winter night. These irregular lights are bright enough to enable the Lapps and the Esquimaux, drawn by their reindeer or their dogs, to traverse the illimitable snowfields which cover their country; and when the absence of the sun tends to sadden their minds, the fitful outbursts of these luminous appearances present them with fantastic forms well adapted to awaken their imagination, which is marvellously exercised thereby."

Although the phenomenon of the polar aurora seems to manifest itself continuously in high latitudes, its frequency is subjected in a series of years and ages to certain irregular periodic changes. A Swedish professor of the last century, Celsius, suspected the possibility of a periodic recurrence, such as has been shown by researches made in recent years to exist. Besides, even on the supposition that the poles of the globe are the seats of perpetual auroras, it would suffice to explain the intermittence of their appearance in our latitudes, if we admit that they are subject to periodic increase in respect of their brilliancy and extent.

Up to this point we have only mentioned the *auroræ boreales* that is those having their seat at the northern region of the earth; those, in fact, which have been most frequently and most easily observed. But there are also *auroræ australes*, southern auroras; but the relative infrequency of navigation in the Antartic seas, the distance of land from the south pole, the consequent absence of fixed posts of observation, and the general foggy state of the atmosphere in those regions, are probably the chief causes of our present lack of information about the auroras. Some austral auroras have extended so far as to be visible in the northern hemisphere; even in Scotland they have been seen; as also certain auroræ boreales have been seen as far south as Peru. At the end of August, 1859, an aurora borealis of great brilliancy was seen in the whole northern hemisphere; at the same time the inhabitants of Chili and Australia observed an aurora australis. This was a very remarkable coincidence,

and it would be very important for the theory of auroras if similar facts had been more often observed. Some physicists, however, consider the simultaneous appearance of aurora borealis and aurora australis to be of general occurrence. This was De la Rive's opinion

§ 5.—*Theory of Polar Auroras.*

All the hypotheses which have been proposed to explain polar auroras may be ranged in two categories, according as their authors have considered auroras as having the same cause as the other phenomena of terrestrial magnetism, or as foreign to these phenomena. We shall only review very briefly the hypotheses of this second category.

Muschenbroeck and Lemonnier thought that at certain epochs there exhaled from the earth, clouds of matter, light enough to evaporate, and then to gather in the upper regions, where this matter, taking fire, becomes luminous and phosphorescent. "The aurora borealis, according to those who hold this opinion, is not a flame like our ordinary fire; but resembles phosphorus, which at first does not shine, and which afterwards gives a feeble light." Euler explained the aurora by the impulsion of solar rays, which project to a distance the particles of the upper regions of the atmosphere and render them luminous by the reflection of the same rays on their surface. The great geometrician opposed this theory to that of Mairan, which remained dominant down to the middle of the eighteenth century; Mairan saw in auroras, as in the zodiacal light, only the effects produced by the penetration of the atmosphere of the sun into the atmosphere of the earth. Lastly, some physicists, like the Abbé Hell, saw in auroras optical phenomena of reflexion, or refraction analogous to those of mock-suns.

It would be superfluous to refute these different explanations, the insufficiency of which is due to the very few exact data then possessed (about a century and a half ago) about the phenomena themelves, and about the circumstance of their production.

We come now to the theories connected with magnetism or terrestrial electricity.

Halley was the first[1] to suspect a relation between the polar aurora and the perturbations of the magnetic needle, but it was in 1741 that two Swedes, Hiorter and Celsius of Upsala, confirmed Halley's views of positive observations.

Wargentin, in 1750, and then Canton and Wilcke, put this idea beyond a doubt. From that time it has been terrestrial magnetism or electricity which has served as the basis of all hypotheses as to the nature of auroras.

Benjamin Franklin stated the matter in his usual terse way by supposing "electrical fire discharged into the polar regions perhaps from a thousand leagues of vapourised air." Eberhart, a German philosopher, and Father Frisi of Pisa, compared the polar light with that which is produced by electric discharges in rarefied gas. Dalton, the English chemist, adopted very nearly the same ideas; he showed by measurement with the theodolite, that the point of convergence of the auroral streamers was in the same azimuth as the magnetic north pole, and he sought to explain this direction of the auroral rays by supposing the existence in high regions of the air, of minute ferruginous particles gifted with magnetic properties. Biot, the French astronomer who had studied auroras in a voyage he made to the Shetland Isles, compared them to true clouds, formed of luminous matter of great tenuity floating in the air. In order to explain the evidently magnetic nature of the phenomena, Biot supposed that these elements are metal particles, and in consequence excellent conductors of electricity. The layers of atmosphere being unequally charged with electricity, columns of these

[1] To explain the aurora, Halley proposed a hypothesis which Humboldt, with reason, called fantastic. According to this hypothesis, there exists in the interior of the globe, between the layers on which the soil rests and the interior solid kernel (equally inhabited by men !), a luminous fluid, which is no other than magnetic fluid. It is the pouring of this fluid through the crevices of rocks and fissures of the soil which, according to Halley, would produce the phenomenon of auroras.

The terrestrial outside covering being less thick at the poles, by reason of the flattening, than at the equator, the fluid finds a passage more easily in the polar regions than anywhere else. Halley also supposed that the rotation of the internal kernel was the cause of the diurnal and annual variations of the declination.

light matters served for electric currents which illuminated their path, as may be seen every time electricity passes through discontinuous conductors. The existence of these columns of matter remained to be explained, and Biot for that purpose invoked the eruptions of volcanoes situated near the magnetic poles. This ingenious theory could not resist the objection raised by Becquerel, and based on this experimental fact, that matter issuing from volcanoes contains no metal particles, but only substances destitute of electric conductivity.[1]

We come now to contemporary theories of auroras, among which we shall analyse the one proposed by M. de la Rive, which is the most generally adopted. First let us quote what Humboldt says in his *Cosmos:* "The aurora borealis ought not to be considered as the cause of the perturbation which troubles the equilibrium of terrestrial magnetism, but as the result of the activity of the globe, exalted to such a degree as to produce luminous phenomena, and which manifests itself, on the one hand, in the polar illumination of the celestrial vault, on the other, by the anomalous oscillations of the magnetic needle. It is seen from this, that the polar light is a sort of noiseless discharge, the act which puts an end to the magnetic storm, as, in electric storms, the destroyed equilibrium is re-established by another luminous phenomenon, namely, the lightning accompanied by thunder." It remains to be shown, if this view of Humboldt's be correct, how to give an account of the stormy magnetic state in which the high regions of the atmosphere are almost always found in the neighbourhood of the two terrestrial poles.

The following, according to M. de la Rive, is the solution of the problem. He considers first that two general points are definitely known in the science: the first is the coincidence of northern and southern auroras; the second point shows what auroras take place in general in the highest regions of the atmosphere, but not beyond. These two points admitted, he thinks that the trade winds carry to

[1] [This is not so, for basalt and volcanic ashes, though much worse conductors than the pure metals, are not perfect insulators. Moreover, hydrogen and other gases emitted from volcanoes, and also the vapour of water, all of which exist in the higher atmosphere, conduct electric discharges when rarefied to a certain degree of tenuity.—ED.]

the polar regions a positive charge of electricity which rises in the air with the vapours of the tropical seas. This electricity, accumulated near the poles, acts by influence on the region of the globe below it, causing it to be negatively charged. Hence a condensation of charges of opposite signs, and a neutralization, under the form of discharges more or less frequent, as soon as a certain difference of potential between the two charges is attained. "These discharges," he says, "ought to take place almost simultaneously at the two poles, since, the conductivity of the earth being perfect, the electric tension ought evidently to be the same, with some slight differences, only proceeding from the accidental variations of the layer of air interposed between the two charges of electricity. And so it happens, that in the earth, during the appearance of auroras, there are two currents going from the poles to the equator; but if the discharge only takes place at one pole, the south pole for example, there is no longer a current in the northern hemisphere directed from the north to the south, but a feeble current directed from the south to the north. This change brings back to the needle of the compass an eastern declination instead of a western one, which happened when the discharge operated from the north pole, the current being directed from the north to the south." De la Rive finds a confirmation of these views, in the variations of direction and intensity which have been confirmed in the earth's currents which trouble the telegraph wires during auroras. Walker and Loomis, who, the one in England, the other in America, have made a particular study of these earth-currents, have found that not only do they vary in intensity, but also in direction, going alternately from north to south, and from south to north. These variations agree with those which the light of auroras presents both as regards their brilliancy, and their perpetual oscillations.

We owe to De la Rive a very interesting experiment, by which he tried to reproduce in its principal circumstances the natural phenomena of auroras. The apparatus which he designed for this purpose (Fig. 69) is composed of a wooden sphere, from thirty to thirty-five centimetres in diameter, representing the earth, and bearing at the extremities of its horizontal diameter two stems AP, A′P′ of soft iron, of eight to ten centimetres in length, and three to four centimetres in diameter. These stems rest on two vertical cylinders of soft iron B, B′, which also serve to support the sphere. The two

cylinders, and consequently the soft iron stems which terminate the horizontal axle of the sphere, can be magnetized, either by surrounding them with a coil transversed by an electric current, or by placing them, as the figure shows, on the two poles of an electro-magnet CC′. The stems of soft iron are enveloped each of them in a covering of glass, sixteen centimetres in diameter and twenty in length, the axis of which they occupy up to the middle. These coverings are hermetically sealed by two metal shields, one of which is traversed in its centre by the soft iron stem, and the other

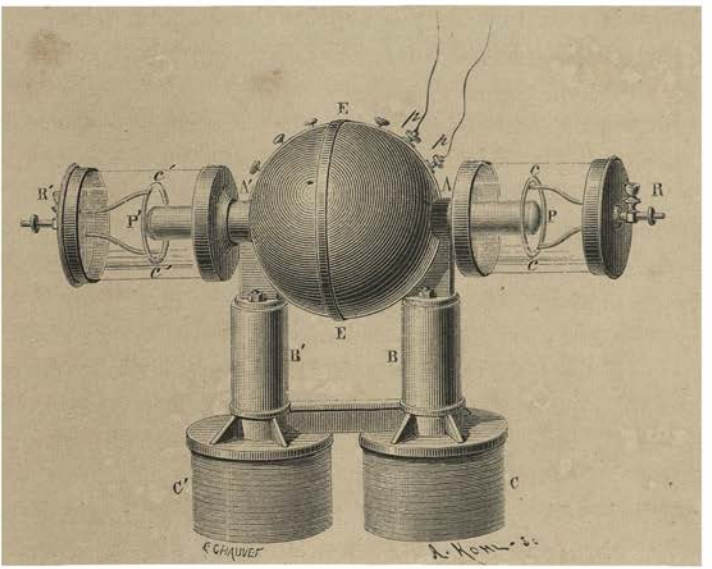

FIG. 69.—Apparatus of De la Rive for demonstrating his theory of polar auroras.

bears inside it, by means of two metal branches, a ring *cc*, *c′c′* also of metal, having its centre on the horizontal axis of the sphere, at the extreme point of the soft iron stem which lies along this axis. Two taps, R, R′ permit of a vacuum being made, and various gases introduced.

To put the apparatus into action the wooden ball is surrounded with two strong bands of blotting-paper, which are firmly secured, one EE all round the equator, the other AEA from one pole to the other. The latter crosses the former, and has its extremities in contact in A and A′ with the soft iron stems. On the second

band are fixed by means of screws a series of little plates of copper *p*, *p*, equally spaced on the same meridian. The wire of a galvanometer, placed at a distance of ten to twelve metres, establishes a metal communication between two of these consecutive plates. The apparatus thus arranged, the bands of blotting-paper are wetted with salt water; then the equatorial band is put in communication with the negative electrode of a Ruhankorff induction-coil, the positive electrode of which communicates, by means of a forked conductor, with the two metal rings placed in the interior of the glass coverings in which the air is rarefied. A discharge is seen to take place under the form of a luminous jet between the ring and the extremity of the soft iron stem; but it is sometimes in one of the glass coverings, sometimes in the other, rarely in both at once, that the jet appears, though the two centres are apparently placed in identically the same circumstances.

"As soon as the soft iron is magnetised," says De la Rive, "the jet spreads out, and forms round the central stem an arch, animated with a movement of rotation, the direction of which depends on that of the magnetism. One important point to observe is, that if the air is not too much rarefied, at the moment when, the soft iron stem being magnetised, the rotation begins, the jet not only spreads out into an arch, but brilliant rays are emitted, which, though perfectly distinct one from the other, turn like the spokes of a wheel with more or less rapidity.

"That is a fairly exact representation of what happens in the aurora borealis, when the auroral arches, animated with a movement of rotation from west to east, dart luminous jets into the high regions of the atmosphere.

"The production of the jets only takes place when the soft iron is magnetised, and it accompanies the movement of rotation; if the air is too much rarefied, it can be brought about by introducing there drop by drop, a volatile liquid, water for example, which vapourises immediately.

"If now we turn to the galvanometer, where the two wires end, which come from the two neighbouring plates, placed on the moistened band that stretches like a meridian from one pole to the other, we observe a derived current, the direction and intensity of which vary, according as the discharge may be taking place at the pole which

belongs to the hemisphere where the plates are placed, or to the other pole. We can also study very clearly the effect due to the secondary polarity which these plates acquire in transmitting the derived current, for that, it is only necessary to stop all discharge.

"By varying the conditions of the experiment, you can reproduce in the movement of the galvanometer placed in the circuit of the conducting wire, all the same variations which constantly accompany the different phases through which the electric discharges of northern and southern auroras pass." [1]

FIG. 70.—Experiment of Gaston Planté. Luminous phenomena of polar aurora; corona.

We owe also to M. Gaston Planté some curious experiments, in which that accomplished electrician by employing the powerful secondary batteries (of which he is the inventor, and which we shall describe in the second book of this volume), reproduces some of the luminous effects of auroras. These experiments suggested to him a theory quite different from that adopted by M. de la Rive; we will say a few words concerning it.

The accompanying cut, Fig. 70, illustrates Planté's experiments

[1] Description of an apparatus which reproduces auroræ boreales and auroræ australes, with the phenomena which accompany them, by M. A. de la Rive. (*Comptes Rendus de l'Académie des Sciences*, 1862.)

on this question. "If," he says, "you put the positive electrode of the powerful secondary battery which I use, in contact with the wet sides of a jar of salt water, in which the negative electrode has been plunged beforehand, you will see, at a greater or less distance from the liquid, either a crown formed of luminous particles arranged in a circle round the electrode (Fig. 70), or an arch bordered with a fringe of brilliant rays (Fig. 71), or a sinuous line which folds backward and forward over itself with great rapidity (Fig. 72). This undulatory movement, in particular, forms a complete analogy with that which has been compared, in auroras, to the folding

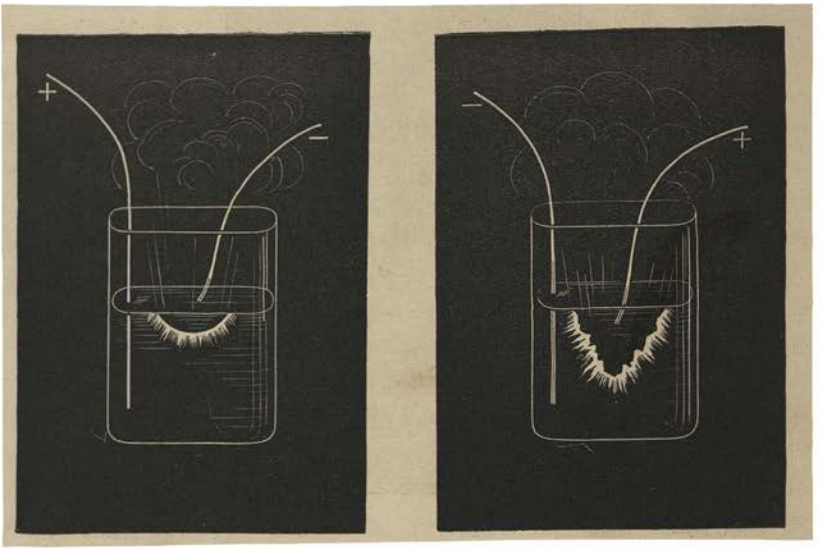

FIG. 71.—Arc bordered with rays.

FIG. 72.—Sinuous arc.

backward and forward of a serpent, or to drapery agitated by the wind."

The light is yellow in consequence of the employment of salt water, but there are purple and violet tints to be seen where the water, coming from the condensed vapour, is less charged with salt.

According to Planté, the dark segment of the auroras has its analogue in the moist segment surrounding the electrode from which the voltaic current spreads. The more this electrode is immersed in the liquid, the more is the latter agitated by the electric current,

and then a luminous ebullition results, which he compares to the fluctuations of polar auroras. The hissing noise which results from this explains what certain observers think they have heard in auroras. The magnetic perturbations which accompany auroras, have their analogies in the agitations of a magnetic needle, placed near a circuit.

"It results from these facts," says Planté, "that auroras may be produced by a flow of positive electricity; for the luminous phenomena are the same as those of the positive electrode in the voltameter, and the negative electrode offers nothing like it."

This also De la Rive admits; but can polar auroras then be, as he supposes, a discharge between the positive charge of the atmosphere and the supposed negative charge of the earth?

This is not Planté's opinion, who, on the contrary, thinks that positive electricity flows towards the planetary spaces, and not towards the earth, through the fogs or icy clouds which float over the poles. He does not regard the equatorial regions as the source where the positive electricity, supposed to accumulate at the poles, is produced, "it comes from a primitive charge, or store of electricity belonging to the earth itself, possessed by it at the origin of its formation, and which tends to dissipate itself, like the heat which it possesses, with extreme slowness, by reason of its considerable mass."

Such are the hypotheses proposed to render a rational account of the magnificent phenomenon of auroras; such are the ingenious experiments by the aid of which their chief features have been reproduced. We confine ourselves to describing them, leaving to physicists the task of discussing them, and of judging how far they appear true.

§ 6.—*Theories of Faraday, Edlund, and Adams.*

Amongst modern theories, those of Faraday, Edlund, and of W. Grylls Adams deserve attention. Faraday's theory, which has lately been revived by Edlund, is based upon the so-called unipolar induction (see Book II. chap. ix.). He considers the earth as a great magnet rotating, and thereby giving rise to currents which flow out of its poles into the upper air, thence returning at the equatorial

regions. The aurora is due to the discharges that constitute a part of these perpetual currents (see *Experimental Researches in Electricity*, article 192).

The theory of Professor Adams is as follows: "As there are tides in the sea around us, and probably in the earth's crust, so there are certainly very large tides in the ocean of air above us; and may not the sun and moon, by dragging this air towards them as the earth revolves, cause that friction between air and earth, and also that evaporation, which together may account for the presence of, and keep up the supply of positive electricity in the air and negative electricity in the earth? Again, these tides in the atmosphere will cause the mass of it to lag behind the revolving solid earth, and at a height of thirty or forty miles we have a layer of air which, for air, is a comparatively good conductor of electricity. Here, then, we have a lagging of the conductor behind the magnet, and hence, according to the laws of Faraday, we may expect a current in the opposite direction to the current in the earth's crust. Thus the regular tidal waves in the atmosphere would cause the gradual transfer of positive electricity from the poles towards the equator. This transfer may be of the nature of a current of electricity or of a mass of air carrying a static charge of electricity with it." "When the air becomes charged up to discharging point, then we may get the sudden discharges such as the aurora in the air and the earth-current in the earth; and since the conducting layer of air approaches nearer to the earth in the colder polar regions, possibly within less than twenty miles of the earth's surface, it may be found that the discharge of the aurora may even take place from earth to air by gradual slow discharge, aided, as it may be, by the state of moisture of the air and by change of temperature and other causes."

[The editor of this translation has sketched out a theory of the aurora which differs somewhat from those of Faraday and of Adams. It is based on several facts of indisputable importance. In the first place there is in all temperate latitudes a great difference between the electric potential of the higher atmosphere and that of the earth, that of the upper air being relatively positive by many thousands of volts. The air which ascends owing to the heat of the sun in all the tropical regions is accompanied by an ascent also of electricity,

possibly due to evaporation going on over land and sea. It is also certain that the heated air so rising parts asunder, some of it going northward in streams which converge towards the north polar regions, some going southward in streams converging towards the south polar regions. The descent of these masses of rarefied air and water vapour occurs at the regions of greatest cold, and the region of greatest cold in the northern hemisphere is known not to be at the geographical north pole, but to be situated much more near to the north magnetic pole, which is also near the centre of the auroral belt or ring. In fact, the region where auroræ are seen in greatest abundance lies symmetrically around the point of greatest cold. Here, then, the positively electrified air and water vapour descends. It is also known that while air at ordinary pressures does not—even though moist—conduct electricity, and whilst very highly rarefied air also is a non-conductor, there is an intermediate degree of rarefaction where discharge readily takes place, as in so-called "vacuum tubes."

There will therefore be, at a certain height in the atmosphere above the earth's surface, a region where, if the air is descending charged electrically, it will discharge itself downwards towards the earth, with a luminosity like that in a Geissler's vacuum tube, but such a discharge will only take place in a layer of a certain altitude and in a region near the centre of greatest cold; and if such discharge is to go on at all regularly it must be accompanied by a corresponding flow of electricity through the earth from the polar regions towards the equator. Such a flow is indeed existent in the feeble daily earth currents which have this direction. Changes in the density of the air due to the shining of the sun will affect the discharge and influence the earth-current. Faraday's theory requires that the earth currents should flow the opposite way. Faraday's theory supposes that the electric phenomena of the earth are due to it being a magnet in rotation. The editor of this work, on the other hand, regards the magnetism of the earth as something that has gradually come about in consequence of the earth's rotation while charged electrically with charges which are being continually caused to circulate under the action of the unequal heating of the sun.]

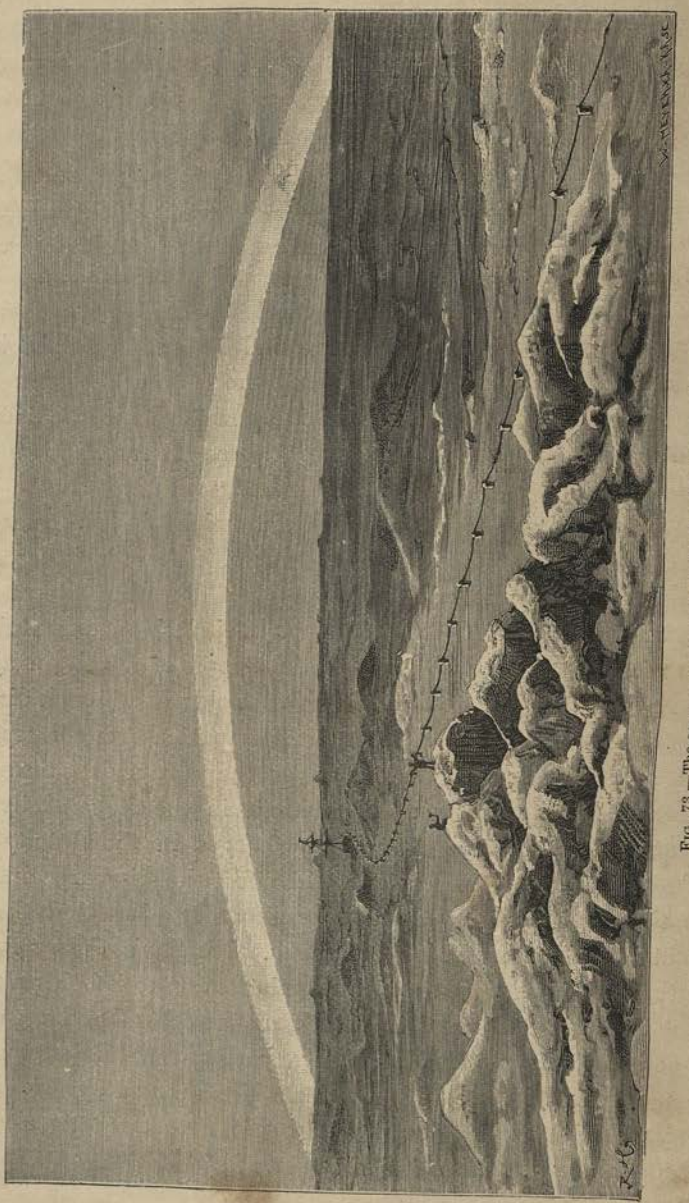

FIG. 73.—The common aurora-arc at the *Vega*'s winter quarters.

§ 7.—*Latest Researches on the Aurora.*

During recent years much important information has been gleaned concerning the aurora by Nordenskjöld, Lemström, Tromhold, and others. An abstract of their results will appropriately close this section.

Commander Nordenskjöld wintered in Behring's Strait during the winter of 1878-9, an epoch at which displays of the aurora were singularly poor throughout the whole arctic region, and had, as seen from Nordenskjöld's vessel, the *Vega*, nothing of the important character which they exhibit in other latitudes in other years.

In consequence, however, of the absence of these extraordinary features, some very definite information was obtained about the simpler, less brilliant, and more ordinary auroral phenomena which appear to persist around the auroral pole. During that whole winter there were seen none of the brilliant and moving phenomena of coruscating arches, flashing streamers, coronæ or draperies. Instead of this, the aurora observed at Kolutchin Bay, in latitude 67° 5′, and longitude 186° 37′ E., was a simple feebly luminous halo-like arc, not distributed into rays. Only once, on March 29th to 30th, did the explorers see any beams of light resembling streamers. The *common aurora arc* which they did see, whenever the sky was clear and dark, rose about 5° to 12° only above the horizon (Fig. 73). It was often accompanied by one or more exterior arcs from which it was separated by a dark strip, sometimes crossed by rays of light flowing from one arc to the other. The exterior edge was not so well defined as the interior, within which lay the "dark segment," or, as Nordenskjöld prefers to call it, the "unlighted segment," of the sky. In one or two instances when a low-lying cloud occupied this part of the sky the light seemed to issue from the edge of the cloud. "I can maintain with full certitude," says Baron Nordenskjöld, "that the lighted segment of clouds which we saw during the winter of 1878-79 had this origin, and most probably, several luminous mists which we saw during the nights of March 18th and 20th, close by our ship, *close to the ice*, were due to the same cause; but I cannot affirm that quite certainly."

His observations led Nordenskjöld to the following conclusions concerning the polar aurora:—

"Our globe, even during a minimum aurora year, is adorned with an almost constant crown of light, single, double, or multiple, whose inner edge was usually during the winter of 1878-79, at a height of about 0·03 of the radius of the earth (120 miles) above its surface, whose surface was somewhat under the earth's surface,

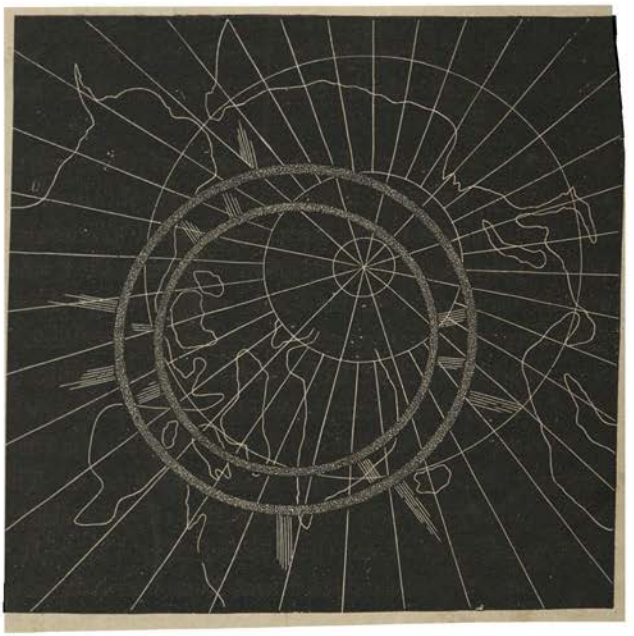

FIG. 74.—Map showing position of the aurora-glory.

having its centre a little north of the magnetic pole, and which, with a diameter of about 0·32 radius of the earth (about 1,280 miles), extends in a plane perpendicular to the earth's radius which passes through the centre of this luminous ring."

Fig. 74, taken from Nordenskjöld's book,[1] will give an idea of this double luminous crown which Nordenskjöld has very aptly named the

[1] A. E. Nordenskjöld: *Arctic Voyages.* The abstract here given is derived chiefly from two articles in *Nature*, January 1882.

"aurora-glory." Of the two luminous rings of the aurora-glory the inner one, or *common arc*, is the most regular and almost permanent. But it is visible only in such parts of the arctic regions as are not inhabited by people of European origin: a circumstance which, together with its feeble brilliancy, may account for the little attention it has received. The centre of the aurora-glory is situated about 81° N. lat. and 80° E. long., being a little north of the magnetic pole, and, as a matter of fact, more nearly coincident with the pole of greatest cold than with the magnetic pole. The outer ring of the aurora-glory is that which is sometimes seen in Sweden, and even in Great Britain, as a faint luminous arch. If the rays which were seen from the *Vega*, flowing from this ring to the zenith, were cast in the plane of the glory, they must have been visible over a circle of over 3,000 miles radius, including California, England, France, and Europe generally as far south as Hungary. Nordenskjöld concludes that there will be five different regions or zones around the aurora-pole where the glory would appear under quite different aspects. In the first region, within a radius of 500 miles of the aurora-pole, it will be visible only as a luminous mist in the direction opposite to the aurora-pole. Captain Nares, who wintered in this region, says: "The phenomena were insignificant in the extreme." The second region is a zone about 500 miles broad, surrounding the first: here the "common" ring of the aurora-glory will be seen as a luminous arch, situated toward the magnetic south: such were observed by Parry. The third zone is only about 250 miles broad. In this region the common arc will appear as a broad, diffuse light spread across the sky overhead, rather than as an arch. The fourth zone is a belt drawn by two radii of 20° and 28° from the auroral pole, its outer circumference being roughly 1,800 miles from the aurora-pole. In this region auroræ usually begin with a luminous bow in the magnetic north, out-spread streamers either into the space beyond them or into the second ring lying beyond and higher above the earth's surface. The fifth region is a narrow belt outside the fourth, crossing Finland, Scandinavia, the extreme north of Scotland, Newfoundland, British America, Alaska, and northern Siberia. The interior circles of the glory are not seen in this region, but only their rays, and the outer circles. The quiet aurora is rare in this region, but it is the

region most visited by auroral storms and outbursts with displays of streamers and drapery.

The researches of Professor Selim Lemström of Helsingfors are of an entirely different order, and date from about 1871, though the most important of them have been made during the years 1882-1885. In 1868 members of the Swedish polar expedition reported an auroral phenomenon consisting of the appearance of faint flames or phosphorescent column above the top of projecting objects, such as mountain cones and ridges. In 1871 Professor Lemström was sent to Lapland by the Finnish Society of Science to examine this phenomenon. Upon the top of Mount Luosmavara, in Lapland, about 520 feet high, was laid out a wreath of copper wire armed with numerous fine points to facilitate an electric discharge. This was connected by a telegraph wire two miles long to a galvanometer, the other terminal of the galvanometer being connected directly to the earth. At night a luminous column appeared above the mountain, which when examined by the spectroscope showed the yellow-green line which is characteristic of auroral light, and at the same time electric currents were observed to be flowing through the galvanometer.

In November 1882 Professor Lemström resumed his researches, and erected on the summit of Mount Oratunturi, distant twelve miles from the observatory at Sodankylä, and more than 1,000 feet above it, a similar arrangement. This apparatus, which its inventor calls an "utströmnings" or "out-streaming" apparatus, consisted of a bare copper wire, to which, at a distance of about eighteen inches apart, small spikes had been soldered. It was erected in twining coils upon poles about eight feet high, provided with insulators, and covered about 1,000 square yards of surface. An insulated telegraph line led down the mountain to a hut, where the observations on the currents were made with a galvanometer. Nearly every night a yellow-white luminosity was seen over this mountain, though there were none above the neighbouring mountains. The electric currents were very variable. Another apparatus on another mountain, Pietarintunturi, gave similar results. Professor Lemström was able to conclude that the aurora is simply an electrical discharge from the upper air, which can be facilitated by using good conductors; that in most winter nights the whole of northern Lapland is illuminated by a phosphorescent luminosity of

auroral nature; and that the terrestrial electric currents, due to the descent of electricity in the belt around the auroral pole, are weaker when one penetrates further within that belt, and probably cease at a certain auroral latitude when one has got right within the inmost belt.

During the winter of 1883–84 further researches were made at Sodankylä, and it was found that the galvanometer could detect the existence of a current between two "outstreaming" apparatuses placed at different levels and connected together by a wire. More important still, Professor Lemström was able, by connecting one of his apparatuses on the top of Pietarintunturi with the negative pole of a Holtz machine at the bottom of the mountain, to produce an auroral column of light above the top of the mountain. The experiment of thus producing an artificial aurora borealis in the sky requires a moonless night, a clear sky, low temperature, and a low barometer.

Dr. Sophus Tromholt, who likewise has studied auroras for many years, has made valuable contributions to recent knowledge.[1] He spent one whole winter in Greenland for the express purpose of studying auroras. The winter of 1882–83 he spent at the Lapp settlement of Koutokaeino for the same purpose. He is led to the conclusion that the auroral zone, the existence of which the observations of Nordenskjöld and others indisputably prove, does not lie quite still, but shifts northward and southward daily to and fro, and that it has a yearly motion, and also a motion which recurs in an eleven-year period. "The aurora borealis," he says, "moves towards the autumnal equinox southwards and northwards, reaching its furthest northern limit about solstice (December 22nd). After this it again moves southwards, being in its most southern position at the vernal equinox, when the movement is in a northerly direction." As to the aurora itself Tromholt says: "In most instances the aurora forms belts or zones, which stretch across the earth in the direction of the magnetic east-west, which zones are formed by a conglomeration of thin sheets of luminous matter ranged one behind the other, their direction being parallel with the dipping needle. The luminous matter in these sheets is either even, diffuse, or divided into streamers. Everything now depends on the position of the observer

[1] See his work, *Under the Rays of the Aurora Borealis*, 1885, edited by Carl Siewers.

in relation to such a zone in order that it may appear in one form or the other. If he be very far from the aurora he will see an arc, diffuse or radiating, according to the nature of the luminous matter. If he approaches he will most probably see several distinct arcs, the phenomenon gathering more force and the colours more life; and, when still nearer, the aurora will appear as a band."

According to Tromholt, in eighteen measurements made on the height of the aurora in the plane from Koutokaeino to Bossekop, the average height of the lower edge of the arc is 113 kilometres, or seventy miles. The separate measurements varied from 70 to 163 kilometres. Recent measurements by Adam Paulsen at Godthaab, in Greenland, gave a lower elevation, the height varying in twenty-two measurements from a maximum of sixty-seven kilometres to 0·6 of a kilometre. From these and the earlier observations it seems probable that the height of the aurora is least in the inner zones, greatest in the outer zones.

[It may be remarked that Dalton estimated the height of the aurora at 241 miles. Backhouse has more recently given as the result of measurements on several occasions heights varying from 81 to 160 miles. Professor Newton, (U.S.) found 130 miles. The measurements of Nordenskjöld vary from 118 to 129 miles.

Respecting the connexion between the aurora and the earth's magnetism it may be noted that whilst Wilcke, the Swede, in 1787 observed that the corona of the aurora forms in the magnetic zenith, it was Ussher who first pointed out, in 1788 that the magnetic meridian bisects the auroral arch.—ED.]

BOOK II.

ELECTRICITY.

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CHAPTER I.

GENERAL PHENOMENA OF ELECTRICITY.

§ 1.—*Electrical Attraction and Repulsion.*

A PIECE of yellow amber briskly rubbed with a piece of woollen cloth has the property of attracting light bodies, such as bits of straw, small feathers, cork, pith, or paper. These things are seen to be drawn towards the parts of the amber that have been rubbed, as if by a mysterious force. This fact has come down to us through countless ages. If it be true that Thales of Miletus, who lived 600 years before the present era, made mention of it, then this is the origin of the science of electricity. But this property of rubbed amber remained only a curiosity for two thousand years. Until the time of Dr. William Gilbert (1600) nobody had attempted to study it in a methodical manner. It is said that many other ancient authors had observed the same attractive power in jet, and also in another substance whose properties are not well known, called by people in olden time lyncurium, which, if it is not a kind of amber, is without doubt a kind of a tourmaline.[1] It does not do to go to the ancients for the explanation of these phenomena. Thales bestowed

[1] According to Th. H. Marten, in his work on *Thunder, the Electricity and Magnetism of the Ancients*, "Diocles and Theophrastus attribute the same properties to lyncurium as to amber. Solin and Priscian, in the British Isles, attribute the same properties to jet (gagates), which is mentioned by them as a precious substance found in those isles."

a soul on amber, just as he bestowed one on the magnet. Pliny is reported to have said that "friction gives amber heat and life."

About the year 1600 Gilbert, who had made several discoveries concerning the properties of the magnet, discovered in glass, sulphur, resin, and various precious stones, the same attractive power known to be possessed by amber. From that time innumerable physicists have extended Gilbert's discoveries, and have found a great number of most curious phenomena previously entirely unknown, and in this way have contributed to found that branch of physics which under the name of *Electricity* has attained such important dimensions in our time. This word *electricity* is used to express more particularly the cause, which even to-day remains unknown, of the phenomena that we are now about to explain.

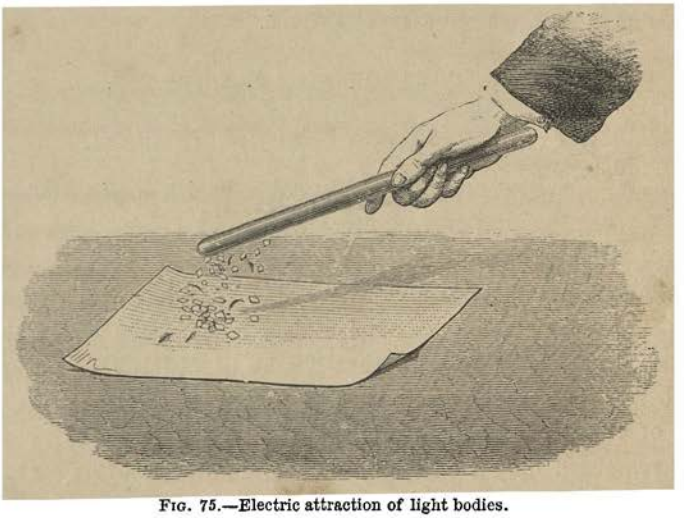

FIG. 75.—Electric attraction of light bodies.

The name electricity is taken from the Greek word for amber,[1] *electron* (ἤλεκτρον).

Nothing is easier than to produce the phenomena of attraction that we have just mentioned. Take a stick of amber, resin, or glass, and rub it quickly and lightly with a piece of cloth. If the rubbed parts be then held near some pieces of straw or paper (Fig. 75) the pieces

[1] Amber is a kind of gold-coloured fossil resin found in considerable quantities on the shores of the Baltic Sea. It has been used for a long time, on account of the beauty of its colour and transparency, for trinkets and necklaces, and also for the mouthpieces of tobacco pipes.

are seen to move toward the surface of the amber or glass, just as scraps of iron are drawn by the magnet. When, however, the pieces touch the rod, some stick to it, whilst others are repelled from it. If the rubbed rod be brought near to one's face a sensation like touching a spider's web is felt. If the stick of resin is a good size, and it be well and energetically rubbed, on bringing the finger near to it a little snap is heard, which in the dark would be seen to be the accompaniment of a small blue spark flashing across between the finger and the nearest part of the stick. The audible snap is the noise of this spark.

A body is said to be *electrified* when it shows these properties to any extent; it is in a *neutral state*, or *unelectrified*, when it shows no signs of attraction or repulsion.

Having laid down the definitions, we will now consider the principal electrical phenomena in the order in which they were discovered, dealing chiefly with the conditions under which they are produced, and entering into some details of the history of the discovery of each of them.

Gilbert did not know of the phenomenon of electrical repulsion, which manifests itself so rapidly after first contact between the electrified body and the light substance that is at first attracted,[1] nor did he know of the reciprocity in attraction between the neutral body and the substance that had been electrified by rubbing. This is the more surprising when we reflect that in order to study these phenomena he used balanced needles, just as he had used balanced magnets for studying magnetism.

If he had used in the same way a ball of glass or sulphur, previously rubbed, he would have known of the reciprocity of attraction, in the same way as he had shown that soft iron attracts a magnet. But Gilbert greatly extended the list of bodies capable, like amber, of being electrified by friction; to those that we have already

[1] The shape of the attracted body exercises an influence on these phenomena. If small round grains or discs are carefully chosen, that is to say, bodies on whose surface there is neither acute angle nor point, repulsion will occur at once after contact has been made. If, on the contrary, the particles are angular, such as bits of feathers, or pointed pieces of paper, repulsion may not be produced. We shall soon see the reason of this difference in the method of producing the phenomena.

mentioned he added shellac, rocksalt, alum, and rock crystal. He also found that electrical attraction took place not only between light bodies, but between certain solid bodies, drops of liquids, gaseous bodies, and dense vapours. Again, he discovered the influence of atmospheric conditions on electric phenomena, which are more marked when there are dry winds blowing from the north-east of Europe, than when there are moist winds from the south and west. Dryness of the atmosphere always promotes the production of electrification.

Boyle discovered the reciprocity of attraction between non-electrified bodies and electrified bodies. A very simple experiment, on the mechanical principle of action and reaction being equal and opposite, led to this discovery. On a pivot was placed a small shellac needle electrified by being rubbed by catskin. Then, on holding his finger near one end, he found the needle drawn towards his finger, Otto von Guericke, who made the first frictional electrical machine, was the first to observe the phenomena of repulsion, and he also drew from the globe of sulphur of his machine visible sparks, accompanied by a crisp crackling sound, which was in fact the noise of the electric discharge. Here we had for the first time in these early experiments the production of sparks similar to those which constitute the electric arc; though it is a long step from these feeble sparks to the dazzling splendour of the electric light. The experiments of the celebrated burgomaster of Magdeburg date from the middle of the seventeenth century. At the commencement of the eighteenth century, that was to witness such brilliant discoveries in electricity, Dr. Wall succeeded in producing most vivid sparks and far louder crackling; he also had some ideas of the great discovery which made Franklin so celebrated. "This light and that crackling," said he, "are the same thing as thunder and lightning." The analogy was indeed striking, and it was not long before it was verified and confirmed.

Numerous observations on the electrical phenomena are due to Hauksbee; among them are very interesting experiments on the light which is produced in a vacuum or in a rarefied medium, when one introduces some bodies into it, and develops on their surface electricity by friction; or when one excites the exterior of a globe of glass, the interior of which is a vacuum.

He observed in particular the effect of heat on the development of both attractive and repulsive forces. The attractions and repulsions

of pieces of tinsel, by a tube of glass, rubbed with paper, were found to be more energetic when the glass had been heated by friction. The effects of moisture and warmth, that Gilbert had discovered, were proved beyond doubt by the experiments of Hauksbee, Dufay, and Gray. The following passage occurs in Hauksbee's *Physico-Mechanical Experiments* (p. 58): "When the tube became hottest by the strongest Attrition, the Force of the Effluvia was render'd manifest to another *Sense* too, namely, that of *feeling*. They did not then only produce all the foremention'd Effects in a more remarkable manner, but were also plainly to be *felt* upon the Face, or any other tender part, if the rubb'd Tube was held near it. And they seem'd *to make very nearly such sort of stroaks upon the Skin, as a number of fine limber Hairs pushing against it* might be suppos'd to do."

As we have mentioned above, Hauksbee compared this sensation to a spider's web, or again, feather-down or cotton-wool.

§ 2.—*Electrical Conductivity.*

The experiments in the preceding section seem to point to two distinct classes of substances, those which are, and those which are not, capable of being electrified by friction. The first class includes amber and jet, later sulphur etc. were added, their number gradually increasing; there were, however, a great number of substances, which, for a long time, under most kinds of treatment, refused to show any signs of electrification. The metals, stones, most vegetable and animal bodies, notably the human body, would not, when rubbed, show the same properties of attraction and repulsion as the substances of the first class. Thus the first class were called by Gilbert *electrics*, and the second, which cannot be electrified by friction, *non-electrics*. This distinction appears most natural, as it offers a striking analogy between magnetic and electric phenomena, corresponding to the distinction between magnetic and non-magnetic bodies, according as they are, or are not, capable of either temporary or permanent magnetism.

The discovery of electrical conductivity was made in the early part of the 18th century, by Stephen Gray. Whilst looking for

the reason of the difference between the two classes, he came upon the general fact, that all bodies, without exception, are capable of being electrified, but that the circumstances must be varied to suit the substances. Let us rapidly review the points that led Gray to this important discovery. Having electrified a piece of glass tube, the ends of which were stopped with corks, he was surprised to find that the corks, which he had not rubbed, picked up light bodies, just as the tube itself did, showing that the electricity passed from the glass to the cork. Gray followed up this experiment by lengthening the corks with sticks of ivory, wood or metal, yet he had the same phenomena even with stems which ended in a ball of ivory. Hung from a balcony by a long cord fastened to the tube the ball still was electri-

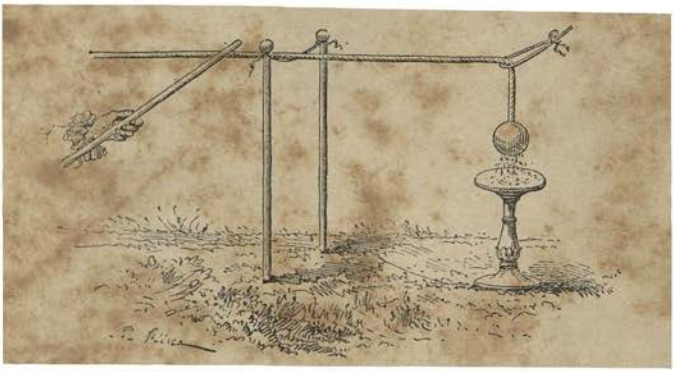

FIG. 76.—Gray's experiment on conduction of electricity.

fied. He then varied his experiment to greater and greater distances, until he found the same effect at the end of a cord 765 feet long. But Gray found that in order to succeed, certain conditions had to be fulfilled; the cord which carried the electricity had to be suspended by silk strings (Fig. 76), as he found that he got no electrification at all if he suspended it by means of metal wires. One more experiment of Gray's that was soon repeated in all laboratories, was to show that the human body conducts electricity; it explains the impossibility that had always been found in trying to electrify such substances as the metals. Having suspended a child by hair cords, as shown in Fig 77, and having touched him with his electrified tube, he found that all parts of the child's body had acquired the power of attracting light bodies. The

same effect was produced when the child stood on a cake of an "electric" substance, such as resin, (Fig. 78) as was produced when he was suspended by the hair cords.

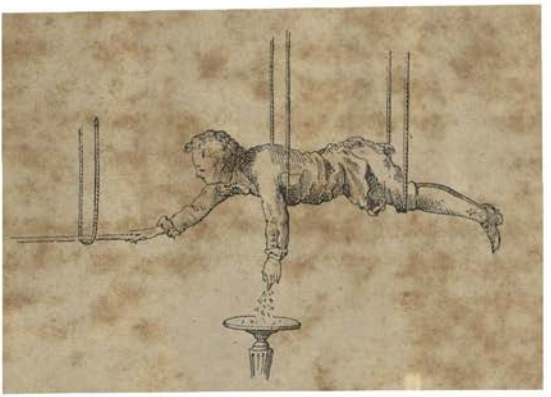

FIG. 77.—Conductivity of the human body; Gray's experiment.

From these experiments, which were then varied in innumerable ways, two very important conclusions were drawn.

The first, that electricity obtained by friction could be transmitted

FIG. 78.—Conductivity of human body. Insulating property of resin.

to a distance through any substance that could not itself be electrified: the second, a corollary to the first, that this transmission is impossible, or very difficult, if the transmitting body is one of those capable of being electrified by the method described above. From this it is concluded

that all bodies can be arranged in two classes according as to whether they will or will not transmit or conduct electricity to a distance. The first class are called *conductors*, the second class *non-conductors* or *insulators*. This last name is given on account of the property of non-conductors to oppose the rapid loss of electricity from an electrified body. Insulation means the cutting off of all communication by which electricity could flow or be conducted away.

This discovery of *electric conductivity* and the conditions which it obtains was of capital importance, and the distinction to which it led, and which we have just mentioned, paved the way to further results of great importance, and to conclusions which could at once be tested by experiments. We must therefore consider it more in detail.

Glass, amber, resin, etc., being bad conductors, electricity should only be developed in the parts rubbed, as indeed is shown by experiment. But if the rubbed substance is touched with the hand (which, like the rest of the body, is a good conductor), the electricity escapes away through it to the earth and so disappears. But it disappears only from those points that have been touched. We have

FIG. 79.—Electrification of a metal.

seen that it disappears entirely if the hand is drawn entirely over the part electrified. We can now understand why, when we rub a metal cylinder, the electricity does not manifest itself, for the metals are excellent conductors. If any electricity is produced it is at once conducted away to the earth. This is proved by fastening a metal cylinder to an insulating handle such as glass (Fig. 79). If it is now held by the glass handle and at the same time rubbed, it becomes electrified, and shows the properties described above more powerfully even than glass, amber, or resin. It is for this reason, then, that bodies which conduct electricity badly are called *insulators*. Every insulator shows signs of electrification on rubbing.

These experiments may be repeated in an endless variety of ways.

If a person stand on a stool with glass feet and be struck with a cat's skin, sparks can be drawn from any part of his body by holding the knuckle near to him; also as long as he remains electrified he will have the same curious sensation as though an electrified body was being held near to him. We quoted above Gray's first experiment which established the electrical conductivity of the body. It was a French physician, Dufay, a member of the Academy of Sciences, who drew the first spark from the human body. "Being suspended by silk cords, he found, when electrified, that, if any one brought his knuckle near to him, he felt a stinging sensation like a pin prick, also that the person's knuckle felt the same sensation. When the experiment was performed in the dark a little spark was observed."

Gray took up the experiments of Dufay, and in his turn found that he could draw sparks from any insulated body which had been put into contact with rubbed glass; if these bodies terminated in a point a small luminous cone was seen, accompanied by a slight noise. In reference to this Gray repeated Wall's comparison between the spark followed by the crackling sound and the lightning followed by thunder.

Water is a good conductor. In the state of vapour it makes the surfaces of things moist and gives them the same property. This is why such great care should be taken, when it is desired to electrify any body, not only to insulate it if it be a good conductor, but to see that it is thoroughly dry. This again is the reason why it is so much easier to produce electricity in a dry than in a wet room: the room where one intends to work should be previously dried, unless upon a day when the air contains very little moisture. To prevent loss of electricity by the settlement of moisture on glass supports, such as are generally used for the purpose of insulating, it is necessary to coat them with shellac varnish or with paraffin wax, which gives a surface that is not hygroscopic like glass.

To sum up: bodies can be arranged according to their conductivity into two classes, *good conductors*, and *bad conductors* (or *insulators*); but in each class it is only a question of degree. Starting with some one body it is not certain that we cannot form a third class composed of bodies whose conductibility is between the extremes; this will be a class of semi-conducting bodies. The follow-

ing table[1] gives a list of substances in the decreasing order of their conductivity :—

Good Conductors.

Metals.	Saline solutions.	Living vegetables.
Gas carbon.	Sea water.	Living organisms.
Graphite.	Spring water.	Soluble salts.
Pure acids.	Rain water.	Linen.
Dilute acids.	Snow.	Cotton.

Semi-conductors.

Alcohol.	Flowers of sulphur.	Paper.
Ether.	Dry wood.	Straw.
Powdered glass.	Marble.	Ice at 0°.

Insulators.

Dry metallic oxides.	Essences.	Precious stones.
Fatty oils.	Porcelain.	Mica.
Vegetable and animal ashes.	Dried vegetables.	Glass.
	Leather.	Agate.
Ice below 20°.	Parchment.	Wax.
Phosphorus.	Dry paper.	Sulphur.
Limestone.	Hair.	Resins.
Chalk.	Feathers.	Amber.
Lycopodium.	Wool.	Shellac.
Caoutchouc.	Silk, raw or dyed.	Air and dry gases.
Camphor.		

The above table, in which we have just arranged all kinds of bodies, solids, liquids, and gases, in the decreasing order of their conductivity, shows that that property varies with the nature of the substances; but it also varies with the conditions, as we will now show. Coke and graphite are good conductors, diamond, which is pure carbon, is an insulator, yet chemically these things are the same. An analogous remark may be made concerning flowers of sulphur and solid sulphur, and about powdered glass and solid glass, also concerning living plants, which are good conductors, and dry wood and mere vegetable matters, which are bad conductors, also water, which is a good conductor in the liquid state, but as ice is a poor conductor, and as dry ice below 20° is an insulator. Thus it depends on the molecular state, whether a body is finely divided or

[1] This table, borrowed for the most part from Mascart's *Traité d'Électricité statique*, is taken from the article "Electricity" in the *Encyclopædia Metropolitana* (London, 1830).

in lumps, its state of dryness or moistness, or its temperature or other such conditions which help or hinder the conduction of electricity through it. Water being a good conductor, we can understand how a body, when perfectly dry, would insulate, but when saturated or covered with moisture would not: hence the above-mentioned precautions in electrical experiments. Heat has also an effect on conductivity, which in some substances increases with the temperature. Canton found that when a glass bottle was heated to 200° C. electricity could pass to the interior. When hot it conducts like the metals, but at the ordinary temperature it is one of the best insulators when dry. Somewhat similar phenomena occur with gases and vapours. If an electrified body be held about one or two metres above the flame of a spirit lamp in connection with the earth, all signs of electricity disappear from the body; all the electricity has been brought to the earth through the column of heated vapours rising from the lamp. If the lamp be insulated from the earth the flame will be found to be electrified and to attract light bodies.

We can now finish what we have to say about electrifying bodies by friction. As regards solids, the only precaution is to insulate them if they are conductors. If mercury be shaken in a glass tube, a glow will be seen on the interior of the tube which is electrified. The same thing occurs if the level of mercury is displaced in a barometer, or if a shower of mercury is made in a vacuum. We shall see later on how a frictional machine for producing electricity may be constructed, in which steam is blown through wooden jets. These experiments prove the production of electricity by the friction of liquids against solids. It is the same with gaseous friction; if a current of air from a pair of bellows be directed against a pane of glass the glass becomes electrified. There seems no doubt then that the friction of a liquid on a gas will produce electricity, but this experiment does not appear to have been conclusively made.

§ 3.—*Electric Attraction and Repulsion. The two kinds of Electrification.*

We must now return to the phenomena of attraction and repulsion and examine them more in detail. For that purpose we shall require a very simple apparatus called an electric pendulum (Fig. 80),

which consists of a small pith ball suspended by a dry thread of silk It is therefore insulated, as dry silk is a non-conductor. If we bring a stick of electrified resin or sealing-wax near to the ball it is first attracted. However, after the ball has touched the stick it is repelled, and cannot be made to come near to the stick. In that state the pith ball is electrified. This is easily shown, as it at once flies to one's finger if held near it, and after being once touched it neither flies to one's finger again nor is repelled by the resin. Whatever electricity it possessed has gone off through one's finger to the earth.

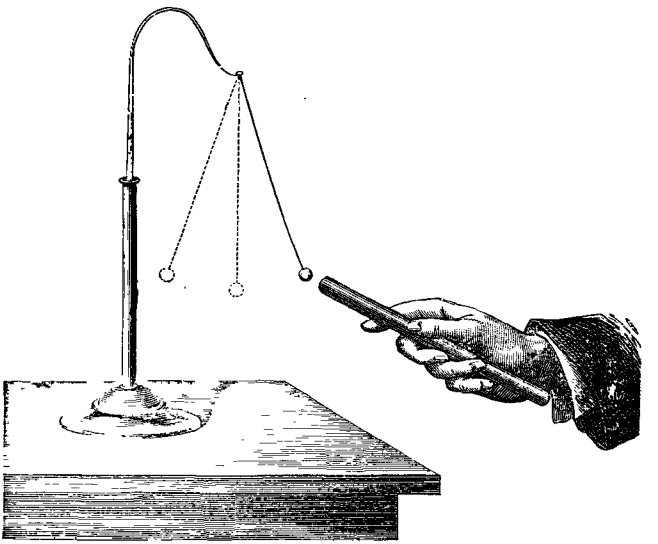

FIG. 80.—Electric pendulum, showing attraction and repulsion.

Suppose the same experiment to be repeated with a stick of glass we shall have the same series of phenomena in the same order, first attraction, then repulsion. So far there is no apparent difference between the electrification developed by the resin and by the glass when rubbed by the same piece of stuff. But suppose after having obtained repulsion with the resin we then bring near the rod of glass, the ball at once flies to it, even more strongly than it did to the resin before it was electrified. The experiment can be repeated in the inverse order, but with the same result. The ball repelled from the glass is attracted by the resin. Let us however modify the experi-

ment by having a double pendulum (Fig. 81), if we then electrify the two balls with the same rod, the two balls will repel one another as soon as they have touched the rod. To perform the inverse of this experiment we must have two single pendulums (Fig. 82), one being electrified by the glass rod, the other by the resin. If now these two

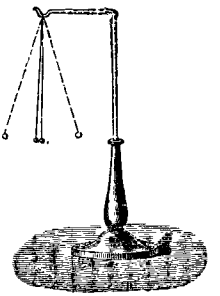

FIG. 81.—Mutual repulsion between two bodies charged with same electrification.

be brought near to each other they will be seen to attract one another.

The foregoing experiments lead us to the conclusion that the electrification of the resin rod is in some way different to the

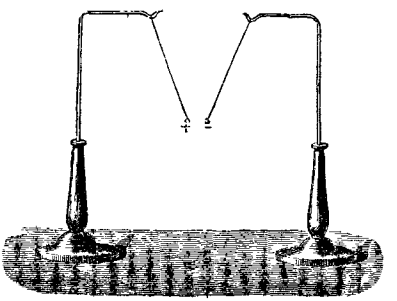

FIG. 82.—Mutual attraction of two bodies charged with opposite electrifications.

electrification of the glass rod, as the electrified ball is attracted by one and repelled by the other. Formerly it was considered that these experiments showed the existence of two kinds of electricity, which received the respective names of *resinous* electricity, and *vitreous* electricity. The more modern view is that

there is but one kind of thing to be called electricity, but that a body can be electrified either positively or negatively, that is to say, by being made either more electrical or less electrical than the surrounding objects. If we repeat the above experiment with a variety of bodies—amber, sulphur, wax, paper, silk, etc.—we shall find that some of them are resinously (negatively) electrified, whilst others are vitreously (positively) electrified.

These earliest experiments are due to Dufay (1733); he made other experiments to determine the difference between the two kinds of electricity. These terms given by Dufay, that we have just been using, are now however given up, for the following reason: All bodies are capable of being electrified by friction, and, as we have seen,

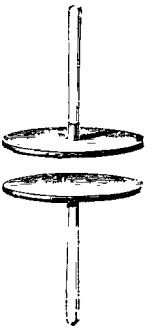

FIG. 83.—Production of both kinds of electrification by friction.

when two bodies are rubbed together both become electrified. But experiment has also shown that the electrification developed on one is not of the same kind as the electrification developed on the other. This is proved by the following experiments: Let us take two discs, one of smooth glass, the other of metal, but with one face covered with silk, and let each be furnished with an insulating handle; if the two are then briskly rubbed together, and then quickly separated, the glass will be found to be charged vitreously and the silk charged resinously (Fig. 83), as can be proved by observing how one is attracted and the other repelled by an electrified ball. But this is not all. We see that the nature of the electricity produced depends not only upon the body which is rubbed but upon the body which rubs. As we have seen, glass rubbed with silk is electrified vitreously,

but if rubbed with cat-skin is electrified resinously; shellac is electrified resinously when rubbed with wool or cat-skin, but if rubbed with rough glass it is electrified vitreously.

If we were to adhere to the names introduced by Dufay, confusion would arise. Hence it is advisable to substitute the terms *positive* and *negative* introduced by Franklin, instead of vitreous and resinous; *positive* being that produced by rubbing glass with silk, and *negative* that produced by rubbing shellac with wool. The action of the electrified bodies upon one another is summed up in the two following laws:—

(i.) *All electrified bodies, whether positively or negatively electrified, attract non-electrified bodies.*

(ii.) *Like electrifications repel each other, unlike attract.*

There are no exceptions to these laws, but the conditions of production of electrification of either kind are very complex, the same substance being capable of being electrified both positively and negatively, depending only on the nature of the body which rubs it. Moreover, the least change in physical state will modify the electrification of a body; difference in colour, polish of surface, temperature etc., cause the same bodies rubbed with the same substance to become first positively, then negatively electrified. Smooth glass rubbed with cloth is positively electrified: but the electrification is negative if the glass is roughened. These results were observed by Aepinus and Canton. Two silk ribbons, one white, the other black, become electrified, the one positively, the other negatively when they are placed together and an ivory ruler is drawn over the surface of one of them.[1] Two silk ribbons drawn across one another, so that the fibres of the surfaces lie across one another, exhibit, the one positive, the other negative electrification. A piece of glass rubbed

[1] We have found in Mascart's *Traité d'Électricité statique* a curious fact, relative to the electrification of silk, observed by an English physicist of the eighteenth century: "Symmer had observed, whilst taking off silk stockings, that they crackled and gave off small sparks in the dark. These phenomena were never so intense as when he had both a black and a white stocking on the same leg. The stockings did not show much signs while on the leg, or whilst together, but the moment they were separated they were powerfully electrified, the white positively, the black negatively. If they were held separated by some distance, they appeared inflated until they showed the shape of the leg. If they were brought near to each other, two of the same colour repelled each other, through an angle of 30° to 35°, and two stockings of different colours attracted each other violently."

with cloth becomes positively electrified, but if the glass be rubbed with emery first, it no longer shows positive but negative electrification. This experiment is due to Heintz. Cat-skin, which is positive to all bodies and especially so to polished glass, behaves differently according as to whether the part used is the neck, or feet, or the back. A number of other curious irregularities have been observed which are just as difficult to explain. Two discs of glass rubbed together show one positive, the other negative, electrification. Heat makes a great difference: the warmer of two substances being usually the negative.

A great number of experiments have been made on the condition of one or other kind of electrification, but little is known on the cause of these curious phenomena, and the theories that have been devised to explain them have only the advantage of arranging them in groups so as to assist the memory in remembering them. What we know from all experiments is, that if a body is electrified by rubbing with another, this latter ought to be electrified, since the two bodies behave in the same way one to the other in the operation of rubbing. When one is going to electrify a glass or resin rod, there is nothing easier than to determine the production of electricity on the piece of cloth or silk held in the hand, as the wool and silk are not good conductors. If the body used to excite the rod were a good conductor, it would then be otherwise, for as soon as the electricity is developed on its surface, it passes off to earth through the body of the operator. For this reason in researches of this kind it is necessary to insulate carefully the bodies employed, if they are conductors. Numerous experiments have been made on different substances to determine the kind of electricity produced in it, by rubbing it with any other of a series of bodies. By this means it has been found possible to arrange all substances in a list, so that any one body is positively electrified when rubbed by any body which follows it, and is negatively electrified when rubbed by any body which precedes it. Experiment has shown that, if a substance, wool or example, is negative when used to rub glass, and positive when used to rub resin, then, *a fortiori*, if the glass and the resin be rubbed together they will be oppositely electrified, and the first will be positively and the second negatively electrified. Remembering that varying conditions vary the electrification of even the same substance, we must not attach too absolute a value to this classification, and the order in the following

list may under different conditions of the experimenting undergo inversions in the sign of the electrification of the bodies included in it:

Classification of bodies according to the nature of the electricity developed by their friction.

Fur.	Rough glass.	Antimony.
Polished glass.	Sulphur.	Silver.
Woollen stuffs.	Aluminium.	Platinum.
Feathers.	Lead.	Mercury.
Wood.	Cadmium. Zinc.	Gold. Palladium.
Paper.	Iron. Tin.	Gun cotton.
Sealing wax.	Copper. Bismuth.	Sulphide of copper.
White wax.		

CHAPTER II.

LAWS OF ELECTRIC ATTRACTION AND REPULSION.

§ 1.—*Neutralisation of Opposite Electrifications.*

LET us repeat the experiment of the two discs, which was described in the preceding chapter. It proves that when any two bodies are rubbed together, and then separated, that they are then electrified with opposite kinds of electricity; but which is positive and which is negative we will now determine, by bringing each disc in turn to the pith-ball of the electric pendulum that has been previously excited. As a result, the disc charged with the same kind of electrification as the ball, repels the ball; but the disc charged with the opposite kind attracts the ball.

We must now try and compare the quantities of the electricity produced on the two discs. For that purpose we shall use an electric pendulum, the ball of which is unelectrified, and is suspended by hemp fibre. Let the discs be now rubbed together, and brought near the ball (Fig. 84); whilst in contact with each other the ball does not move, and there is no more effect than if the discs were unelectrified. If, however, they are separated and brought near to the pendulum again, without being rubbed again, it will be seen that each one of them will attract the ball. (Fig. 85.)

Thus, not only does rubbing two bodies together produce both kinds of electrification, but it produces them to the same extent. The two equal and opposite forces, acting at the same point, destroy one another.

An old experiment, due to Æpinus, showed at the same time the production and neutralisation of the two kinds of electrification.

Melted sulphur was poured into a metal vase, standing on an insulating stand. When the sulphur had set, there was no sign of electrification, but, if the sulphur be lifted out by a wire inserted

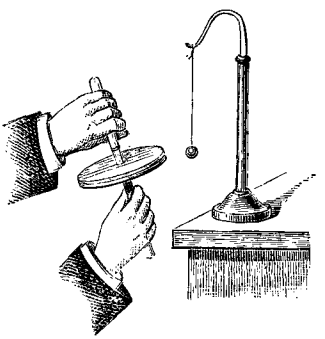

FIG. 84.—First experiment on neutralisation of opposite electrification.

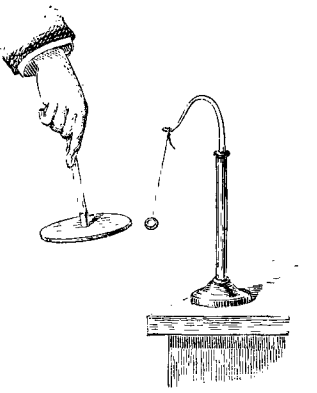

FIG. 85.—Second experiment on neutralisation.

during cooling, the vase was found to be electrified negatively, and the sulphur positively. Again, if the sulphur be replaced, all signs of electrification disappear.

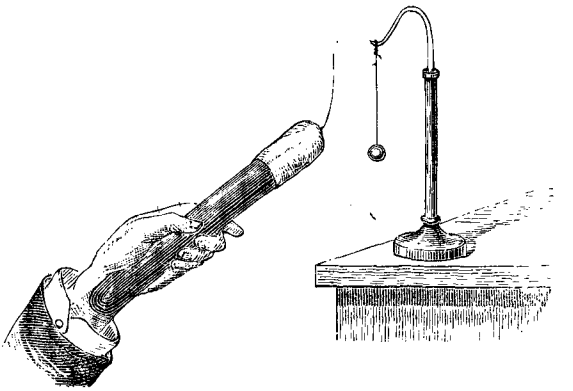

FIG. 86.—Faraday's experiment.

Faraday's experiment illustrated in Fig. 86, exhibits the same more simply. It consists in rubbing a stick of sealing wax or shellac, with a silk hood, attached to a silk thread. If the stick be now brought

near to the ball with the hood on, no trace of electricity can be observed; if, however, the hood be withdrawn, the rod is seen to be electrified, and the hood also in its turn is found to be electrified, thus showing the electrifications produced by rubbing one body on another are equal in quantity and opposite in sign.

We have thus proved a very important fact: the quantities of electrification developed by the friction of two bodies one against the other, are equal and opposite: they are equal to one another, and neutralise each other, it is this which justifies the names of *positive electrification* for one, and *negative electrification* for the other.

We now ought to define electrical quantity, but we will first describe the theories adopted to explain and account for the various phenomena of electricity.

§ 2.—*Theory of Electric Fluids.*

In ancient time, the only phenomenon of electricity that was known, was the attraction of amber for light bodies. To explain this, they proposed theories similar to those which they suggested about the magnet. Thales said that amber had a soul, just as he had said that a magnet had one; in other words he acknowledged the existence of a force peculiar to each of these substances; which idea was very natural, although fruitless. We must come as near as to the seventeenth and eighteenth centuries, before we find even crude theories of any interest concerning electricity.

Gilbert is accredited with the following hypothesis: friction, because it heats a body, causes it to emit rays of a subtle unctuous material, which is cooled again on coming into contact with the air, loses its expansive force, and draws itself together again, bringing back such light bodies as come in the way of the electrified body. An almost similar hypothesis to this was brought out by Boyle; with this difference, that the return of the material rays, sent out by the electrified body, is, according to Boyle, somewhat modified by the reaction of the surrounding air, or by the resistance of the air to the vortices of moving matter. According to Hauksbee, the emanations of matter which start from an electrified body spread in the form of rays or physical lines, which possess a kind of con-

tinuity in themselves, so that those parts of each ray or line which reach out furthest into space receive the impulse from those parts which are nearest to the body. The contiguous air is thus rarefied in the direction of the divergent lines of the *effluvia;* it is compressed in the opposite direction, that is to say, in the direction of the convergent lines, by the more remote and denser air. Hence the motion imparted to the light bodies, tending to move them nearer to the electrified body. The Abbé Nollet held that all bodies capable of being electrified by friction, were filled with matter that tended to escape through their surface; it is the pressure due to the rubbing, that makes the electric matter that is shut up in the glass, ooze through the surface. The resistance of the air that it must pass through, in coming through the pores of the glass, makes it scatter itself in diverging rays which fill a certain range less extended in size, according to the degree of activity of the body electrified, and of the fluid put in motion. This substance which is given off by the electrified body, leaves there vacua which are immediately filled up by a fluid of the same species as that which surrounds it. This is then the electric substance which acts in two opposite ways, and which forms, so to say, two currents, one from the body by divergent lines, and the other to the body by convergent lines.

These hypotheses have long been abandoned; they answered their purpose until numerous additional phenomena were discovered, which were incapable of being explained by such crude theorising. Two principal theories have taken their places. Physicists have adopted either one or other of them, for most of the phenomena of frictional electricity can be explained, in simple language, in accordance with either of them. The first of these is known as Franklin's *One Fluid Theory,* the second is Symmer's *Two Fluid Theory.* We will now discuss them. The following is Franklin's opinion on the nature of electricity.[1]

1. "The electrical matter consists of particles extremely subtile, since it can permeate common matter, even the densest metals, with such ease and freedom as not to receive any perceptible resistance."

[1] *Opinions and Conjectures concerning the Properties and Effects of the Electrical Matter, arising from Experiments and Observations made at Philadelphia,* 1749, p. 54.

2. "If any one should doubt whether the electrical matter passes through the substance of bodies, or only over and along their surfaces, a shock from an electrified large glass jar, taken through his own body, will probably convince him."

3. "Electrical matter differs from common matter in this, that the parts of the latter mutually attract, those of the former mutually repel each other. Hence the appearing divergency in a stream of electrified effluvia."

4. "But though the particles of electrical matter do repel each other, they are strongly attracted by all other matter."

5. "From these three things, the extreme subtilty of the electrical matter, the mutual repulsion of its parts, and the strong attraction between them and other matter, arise this effect, that when a quantity of electrical matter is applied to a mass of common matter, of any bigness or length, within our observation (which hath not already got its quantity), it is immediately and equally diffused through the whole."

6. "Thus common matter is a kind of sponge to the electrical fluid. And as a sponge would receive no water if the parts of water were not smaller than the pores of the sponge, and even then but slowly, if there were not a mutual attraction between those parts and the parts of the sponge; and would still imbibe it faster if the mutual attraction among the parts of the water did not impede, some force being required to separate them; and fastest, if, instead of attraction, there were a mutual repulsion among those parts, which would act in conjunction with the attraction of the sponge—so is the case between the electrical and common matter."

7. "But in common matter there is (generally) as much of the electrical as it will contain within its substance. If more is added, it lies without upon the surface, and forms what we call an electrical atmosphere; and then the body is said to be electrified."

8. "'Tis supposed, that all kinds of common matter do not attract and retain the electrical, with equal strength and force, for reasons to be given hereafter. And that those called electrics *per se*, as glass, etc., attract and retain it strongest, and contain the greatest quantity."

9. "We know that the electrical fluid is *in* common matter

because we can pump it *out* by the globe or tube.[1] We know that common matter has near as much as it can contain, because, when we add a little more to any portion of it, the additional quantity does not enter, but forms an electrical atmosphere. And we know that common matter has not (generally) more than it can contain, otherwise all loose portions of it would repel each other as they constantly do when they have electric atmospheres." . . . . . .

15. "The form of the electrical atmosphere is that of the body it surrounds."

Such are the essential parts of the primitive theory propounded by Franklin for the purpose of giving a consistent account of the phenomena of electric attraction and repulsion so far as they were known in his time. The theory assumes the existence of one electric substance or fluid which attracts the particles of ordinary matter, but repels itself. In the ordinary state, bodies are charged with a normal quantity of this electrical substance. If this charge be either increased or decreased, the body becomes "electrified;" if it be increased, the body is charged with a *plus* or *positive* charge; if the body has a less quantity of electricity than in its normal state, it is said to be charged with a *minus* or *negative* charge.

This theory is completed by the law discovered by Coulomb, which we will now state: The electrical attractions or repulsions vary inversely as the square of the distance between the two electrified bodies. This theory of Franklin's was at one time, and is still on the Continent, less generally accepted than Symmer's two-fluid theory, which we shall now take up.

The theory thought out by Symmer supposes that instead of there being one fluid there are two electric fluids having opposite properties to one another. The molecules of either fluid repel each other, but attract those of the opposite kind of fluid. Bodies in their normal condition, or when un-electrified, contain equal quantities of both fluids held together by their mutual attraction, so neutralising one another. By friction, or by other means that we shall presently describe, we are able to separate the two fluids; the "positive" fluid passes to one of the bodies and accumulates on its surface; the

[1] Franklin alluded here to the two modes of producing electricity then known; the friction of a globe of sulphur, or resin, or glass, and that of a tube of glass.

"negative" fluid passes to the other of the two bodies, so that when separated they are found to be charged with opposite electricities; but if after rubbing them together they are left in contact, the electricities disengaged neutralise one another. The attraction of molecules of the opposite fluids, and the repulsion of molecules of the same fluid, explain the phenomena of attraction and repulsion between electrified bodies; the movements of the fluids giving rise to movements of the material particles, either by the pressure of the surrounding medium upon the molecules, if we suppose in our theory that the fluids have no direct action on the molecules of ponderable matter, or else by the direct action of the fluids, if we make the supposition that each fluid directly attracts the molecules of matter.

There is a close analogy between the two-fluid theory of electricity and the theory of the two magnetic fluids; but in the case of magnetism the separation of the fluids, which characterises magnetisation, only occurs within the molecules of the magnetic body; each of these molecules always containing the same equal quantities of the fluids when separated. On the other hand the electric fluids, when separated, can pass from one molecule to another. But mere analogy must not be carried too far. The rival theories of Symmer and Franklin are equally satisfactory in explaining the facts of observation. Which of the two is the true one? Are there two fluids, or is there only one? Or can one imagine that there already exists in nature a medium possessing special properties to which the phenomena of electricity are due? All modern physicists agree in regarding these fluid-theories only as a convenient means to convey in a clear and concise way the relations between the facts. Instead of trying to multiply the number of natural causes, they seek rather to trace all such natural forces to one common cause. In the correlation of natural forces we recognise the existence of *matter* as a thing by itself, which can neither be created nor destroyed, however much it may be changed in form. Also we recognise the existence of *energy* as a thing by itself. But matter and energy are not enough to explain the phenomena of light or of electricity. There exists something else,—an all-pervading medium. This medium we denominate the *ether;* it is the vehicle of light-waves and of radiant heat. There is little doubt that this medium it is which gives rise to electric and magnetic phenomena. Indeed, many physicists hold that *the ether is*

electricity. The following is what M. Briot says in his work on the *Mechanical Theory of Heat*:—

"If one adopts as the more probable, the one-fluid theory, it is natural to suppose that this fluid is none other than the ether, by the vibrations of which we explain the phenomena of light. Experiment, however, tells us that in the vacuum no electrical phenomena occur; that is to say, in the absence of all ponderable matter there is no electrical manifestation. It seems from this that we ought to estimate as the electric fluid contained in a given volume not by the total quantity of ether that it contains, but by the sum of the atmospheres of ether which surround the ponderable molecules, that is to say, the excess of the total quantity of ether that the volume contains over the quantity which would be contained by the volume of the ponderable molecules.[1] To explain electric phenomena, we must admit that ponderable matter attracts ether in the inverse ratio of the square of the distance, and that the mutual action of two atmospheres of ether is also proportional to the product of their masses and to the inverse ratio of the square of the distance between them."

[At this point of his work the author makes the statement that as the two-fluid theory is used by the great majority of electricians, he will adopt its language in his work. This statement, though it may be true of French electricians, is certainly not true of the great majority of English electricians, and probably will not be true of French electricians ten years hence. In fact, the doctrines of energy have compelled more rational views. That there should be two substances, one of which should be the negation of the other, so that on mixing the two there should be none at all discoverable, is inconceivable.

It would hardly be just to the general reader to permit him to pass from this point without adding for his guidance a word on the modern views concerning the relation of electricity and energy. Every electrical action is also in the truest sense of the word an exhibition

[1] We are here supposing that the action of ponderable matter on ether is attractive; each ponderable atom, being surrounded with an atmosphere of ether density, of which is greater than in vacuo, but decreases rapidly from the centre: the excess of ether accumulated about each atom is reckoned as the mass of that atmosphere.

of energy. The science of electricity is only a part of the much wider science of energy, exactly as the science of mechanics is only a part of the science of energy. To lift a weight, to bend a spring, to impart motion to a projectile, all require the expenditure of energy. Yet these actions are all, as we commonly say, purely mechanical. All mechanical work that is performed, that is to say all work that is performed in the way of moving matter against mechanical forces, is done by expending energy. Just so all electrical operations, such as the moving of electricity along a wire as a so-called electric current, or squeezing a charge of electricity against the surface of a non-conducting plate of glass (as is done in the operation of charging a Leyden jar), or the forcing of a small quantity of electricity in the form of a spark through air or oil or other non-conducting medium,—all such electrical operations require the expenditure of energy. Energy must be expended if matter is to be moved against mechanical forces: energy must also be expended if electricity is to be moved against electrical forces. In the case of matter there is a law of self-attraction—the common law of gravitation. Matter attracts itself: *therefore* we have to spend energy in the operation of lifting up any mass of matter from the earth. In the case of electricity there is a law of self-repulsion, inevitably tending to make electricity distribute itself uniformly throughout all space: *therefore* we have to spend energy in the operation of altering this normal distribution. And in every case, whether mechanical or electrical, when work has been done by the expenditure of energy, the body or system of bodies on which this work has been done possesses, in some form or other, the energy thus imparted to it, and is able (in most cases) by virtue of the energy thus imparted to it, to do, in its turn, work of some sort which otherwise it could not have done. The lump of matter which has been lifted can fall down again, and in falling can drive machinery (such as a clock), or can do other mechanical work (such as pile-driving, crushing ore, etc.) The spring which has been laboriously bent, can unbend and do work in turn. The projectile which has been set flying can deal out destructive work because of the energy of motion which it possesses. So also the current of electricity which has been set flowing in a wire (at the expense of the energy of the battery) can drive a motor or provide light or heat. The charge of electricity which has been squeezed against the glass of the Leyden jar can rush

back and produce a forcible discharge accompanied by a spark or by a very unpleasant shock to the person upon whom the stored energy happens to be expended. The careful student of electricity should be able to assign to every electrical action a similar explanation in accordance with the doctrine of energy. It is of little moment in comparison whether electricity is regarded as *one* or as *two*. *Whatever electricity itself is, the one important thing of which we are certain is that every electrical action is accomplished by the expenditure of energy; that is to say, is accomplished by the transference of energy from one part of the system to another.*—ED.]

§ 3.—*The Laws of Electrical Attraction and Repulsion.*

Whatever may be the idea formed of the nature of electricity itself, there is no doubt that it causes the occurrence of forces of attraction and repulsion. Our natural inquiry is, what are the laws of these forces; or in other words, how do these attractions and repulsions vary when the distance between the two bodies is varied; and how do they vary when the quantities of the respective charges are varied? Newton's grand discovery of the law of universal attraction of matter, when he showed that the force was proportional to the mass and that it varied in the inverse ratio of the square of the distance, incited the physicists of the eighteenth century to discover the law which governed the strength of electrical forces. Dufay, Hauksbee, Muschenbroek, Aepinus, and Cavendish, were all more or less instrumental in attaining this end; but we are indebted to Coulomb for an exact experimental demonstration of these laws. Coulomb used for this purpose a similar apparatus to the magnetic balance. It was constructed on the same principles and had the same general arrangement, differing only in the nature of the bodies used, that is to say, in the nature of the forces that he was measuring. This electrical balance is shown in Fig. 87, which the reader should compare with Fig. 26, p. 30. The suspension-thread fixed to the micrometric head is a very fine silver wire, carrying suspended a horizontal needle of shellac (f). One of the ends of this lever is terminated by a small ball of conducting material, or by a small vertical disc of gilded paper (g), whilst the other end acts as a counterpoise.

The centre of the disc lies in the plane of a divided circle, engraved around the glass shade which supports the thread; a second stick of shellac (f') terminated by a ball of conducting material (g') is fixed vertically in the glass cage in such a way that the centre of the ball is in the same horizontal plane as the centre of the disc (g), and that the vertical plane containing the rod (f') and the suspension thread are in the plane of the zero of the scale.

We will now describe how to determine the law of the variation of attraction or repulsion with the distance. The disc is first brought into contact with the ball without there being any torsion in

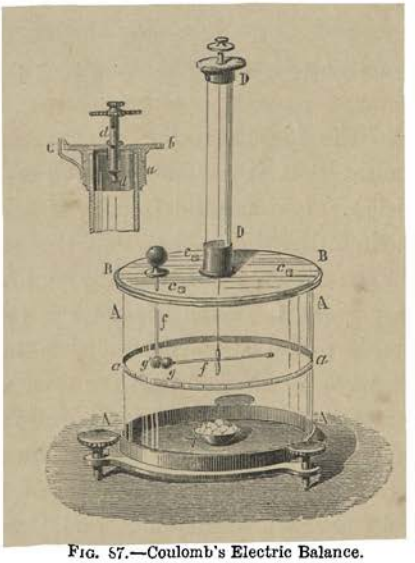

FIG. 87.—Coulomb's Electric Balance.

the thread, the ball (g') not being yet electrified. The rod (f') is then withdrawn and the ball on its end is electrified; it is then put back into its place. The disc of gilt paper being in contact with the ball becomes charged with the same electricity; immediately repulsion causes a separation to a certain distance which is measured on the divided scale. Suppose for example that the separation is observed to amount to 36°. The disc has however in being repelled twisted up the thread, and the torsion force, which is equal and opposite to the repelling force, is exactly measured by the angle of 36°, since, as we have seen before, the force of torsion is proportional to the angle of

torsion. If the micrometer-head is then turned round backwards way so as to force up the disc to half the distance, that is to say to 18°, to accomplish this it will be found necessary to turn the head through an angle of 126°, the total force of torsion (or what comes to the same thing, the electric repulsion which balances it), is measured by the amount of twist on the suspension thread. The lower end has now we know a twist of 18° to the right. The upper end has a twist of 126° to the left. The total twist on the thread is therefore $126° + 18° = 144°$. To reduce the distance to one quarter or to 9°, the micrometer-head must be turned through 567°, the repulsion then is measured by the number $567° + 9° = 576°$.[1]

The result is that when the distance between two electrified bodies varies in the proportion of the numbers 1, $\frac{1}{2}$, $\frac{1}{4}$, the electric force is represented by the relative numbers 36, 144, and 576, or the numbers 1, 4, and 16. Hence the law :—

The repulsion between two electrified bodies charged with the same electricity varies inversely as the square of the distance between them.

The law of attraction might be proved by a similar experiment to the above, only the suspended rod of shellac should be placed at a fixed known distance from the ball. They would then be charged with opposite electricities, whence a motion of attraction will take place between the disc and the ball until the force of attraction balances the torsion. The experiment would then be repeated, the distance between them being varied and the torsion in each case measured. The result would be found the same as for repulsion, only unfortunately in the case of attraction the equilibrium is always unstable and the chances of error in observation are enhanced a thousandfold. We may, however, formulate the law in this more general way:

Electrical attractions and repulsions vary in the inverse ratio of the squares of the distances which separate the electrified bodies.

Coulomb verified the law of the electric actions by a second

[1] In reality Coulomb and the other physicists who have verified this law did not obtain such absolutely correct figures as we have given. The slight differences observed were such as would occur during the experiment, from the loss of charge on the ball or disc, in consequence of the imperfection of the insulation. Coulomb reduced this cause of error by placing in the glass-case some fragments of quicklime or calcium chloride to absorb the moisture.

method, the method of oscillations of which we spoke (p. 32) when dealing with experiments relative to magnetic attraction and repulsion. He caused a shellac rod terminated by a disc of metal (Fig. 88) to oscillate at various distances from a conducting ball charged with electricity. He then counted the number of oscillations made in a given time; from this he determined their period. He found that the periods of the oscillations were proportional to the distances. But as the forces producing oscillations such as those of the pendulum are known to be in the inverse ratio to the square of their periods, it follows that the electrical actions vary in the inverse ratio to the square of the distances between the two electrified bodies.

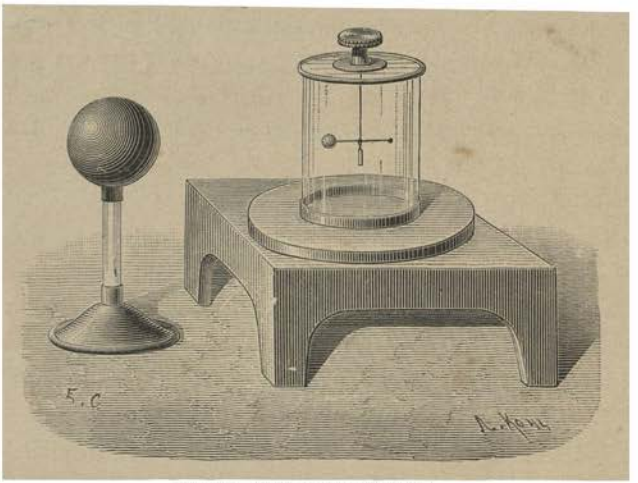

FIG. 88.—Method of oscillations.

In all the preceding experiments we have supposed that the charge on the electrified body remains constant throughout the experiment. It only remains to be known what the effect is of varying the quantity of the electric charge on the two bodies which exercise either an attractive or repulsive effect on each other.

But for that purpose we ought to explain what is meant by the *charge* or *quantity of electricity*, or, to conform to scientific language, what is meant by *electrical mass*.

In considering electricity as a fluid distributed throughout a space or spread over the surface of an electrified body, one must admit that if two spheres, equal and similar in all respects, one of which

has been previously electrified, are put into contact, they will divide the electricity equally between them.[1] Their electrical charges are then equal, each of them has half the electrical charge contained in the single sphere before contact. Coulomb showed that this equal division of the electrification takes place between similar conductors whether they are of the same material or not. The definition of double, triple, &c., electric charges is the result of that definition of equal charges. Coulomb showed experimentally by the aid of the electric balance, that :—

The attractions and repulsions vary in the ratio of the products of the quantities of free electricity, that is to say of the electric charges of the two bodies. The laws that we have just enunciated are only exact for bodies whose dimensions are small compared with the distance between them.[2]

The experimental demonstration of the laws which govern electric actions, to be perfectly accurate should be made with quantities of electricity, which are absolutely constant throughout the experiment, or at least if they vary, their changes should be absolutely known. In reality, as Coulomb found, all electrified bodies are subject to gradual loss of charge with time. The reason of this decrease is easy to understand. In vain are electrified bodies insulated by the aid of supports made of non-conducting materials; in vain the air in which they are used is dried as perfectly as possible; the electric charges still spread through these contiguous bodies, and thence escape to the earth.

In truth no substance that we have classed in the foregoing lists, according to the degree of their conductivity, is a perfect insulator. Here then is the chief source of the loss of electricity, for the less the conductivity of the supporting substance, the less the rate of loss. Shellac, especially brown shellac, is the best insulator; but then the

[1] According to Coulomb, the charge not only divides itself equally between two spheres of the same radius, but also between any two equal and similar conductors of any form. Only, in that case, it is necessary that they are put in contact at two points, such that they are symmetrical on each side. If the bodies are only poor conductors, contact must be made for some time.

[2] This second law is self-evident if we adopt the general mechanical definitions for electric charges, that is to say, if we consider the quantities of electricity, or the electric charges, as proportional to the forces, then the result of Coulomb's experiments is that the division of the electricity between equal or identical conductors is as was stated *à priori* by that physicist.

surface must be perfectly dry. But this will only remain so for a short time, as its surface is slightly hydroscopic; water-vapour condenses on it, from air forming a film of moisture, which is, as we know, a good conductor of electricity. For this reason Coulomb placed in his balance some quicklime or chloride of calcium, so as to keep the air in the case thoroughly dry. Paraffin wax is an admirable insulator when pure. It does not attract moisture; but it must be kept free from dust. The loss of electricity due to the air can be assigned to two causes. In the first place, though gases have in themselves a very slight, practically no conductivity at all, they nevertheless cause loss when moist, and it rarely happens that gases are free from moisture. The fact that electric machines will scarcely work in a damp atmosphere, that damp air favours the loss of electricity, is beyond dispute; but is this due to the true conductibility of damp air? This is what we have believed and taught for a long time. But the result of experiments made by the late Count du Moncel, by M. Gaugain, and more recently by M. Marangoni, shows that this is not true. Damp air is not a conductor; the losses which it occasions, in telegraph wires for example, are by the film of liquid which condenses on the surface of the insulating supports, not by a direct propagation of electricity, through the films of air. In the second place, the molecules of air near to the surface of an electrified body are drawn into contact with it, and then are repelled, because they have been electrified by the contact. Others then replace them, and so the loss goes on gradually weakening the charge, and finally dispersing it.

We can now understand the importance of taking proper precautions for eliminating these sources of error whenever very delicate experiments are to be made, especially when an absolutely known quantity of electricity is required to be used. Sometimes it is necessary to check the losses which arise from forgetting these precautions. In every case these losses must be taken note of, and for this purpose we must know the laws which govern them.

Coulomb and several contemporary physicists, Matteucci, Gaugain, Riess and others, studied these laws; the following are the chief results of their researches. Concerning the supports, Coulomb found that a pith ball ten or twelve millimetres (about half an inch) in diameter, can be perfectly insulated by supporting it upon a cylinder

of shellac 1 mm. in diameter and 4 or 5 cm. long. The same result can be attained by suspending it by a long, very thin, silk string, or a thread of glass, which whilst hot, is drawn through melted shellac or paraffin wax.

Temperature greatly influences conductivity, as for example a substance which insulates at the ordinary temperature will gradually conduct more and more as the temperature is raised. Tourmaline at ordinary temperatures insulates, but at a temperature of about 400° or 500° it is said to be a good conductor. Gaugain has observed that if tourmaline be so heated, it becomes hygroscopic, which property it does not lose on cooling. When this is so it must be re-heated in a dry heat to 150° before it loses this property and again becomes an insulator.

Glass when heated so as to become soft, conducts, and is electrolysed.

Concerning the air or surrounding medium, Coulomb found that the electrical loss increased with the moistness of the medium, and also with the amount of the charge, or the state of electrification of the body. According to Matteucci the loss is less in moving air than in still air, independent of the charge, between certain limits, and when the gas used is dry and pure, the loss for moderate degrees of electrification is independent both of the nature of the gas and of the electricity (whether positive or negative). The loss increases with the temperature in dry air, and it varies with the pressure.

§ 4.—*Distribution of Electricity on the Surface of Conductors.*

When a body not a conductor, *e.g.*, a stick of resin or glass, is electrified, the parts that have been rubbed or the parts put in contact with an electrified body, alone are electrified. In this case, as we have just seen, the electricity spreads itself over the surface very slowly, but with a conductor it is different, the electricity instantly diffuses itself all over the surface, but the question arises does the electricity spread itself through the interior and how is it distributed over the exterior?

We have already described how Coulomb put two spheres of the same size in contact, and then found that the charge had equally

divided itself between them, whatever they were made of. It follows that the final redistribution is not affected by anything inside of the bodies, but depends only on their surfaces.

We will now prove this in another way.

A metal sphere on an insulating stand is covered by two moveable hemispheres, each provided with an insulating handle. The whole arrangement is now electrified; whilst in this condition the two hemispheres are removed at the same time (Fig. 89). On bringing each of the parts in turn to an electroscope of any kind, the two hemispheres

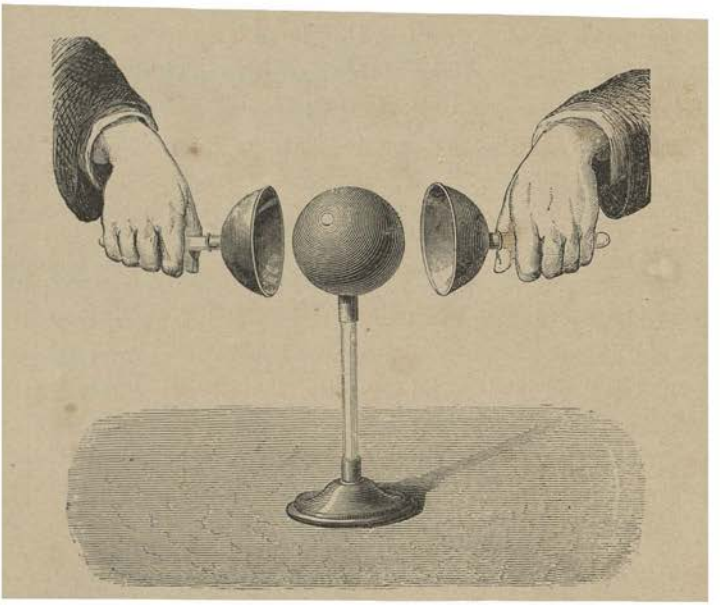

FIG. 89.—Distribution of electric charge on surface of bodies. Biot's apparatus.

are found to be electrified, but the sphere itself is not electrified. The electricity has not even penetrated through the thickness of the hemispheres.

Let a wide ribbon of tin foil or tinsel be fastened to an insulating cylinder, so that it can be rolled or unrolled by a handle; let there be at its free end two pith balls (Fig. 90) attached by thread. Now let the foil rolled upon the cylinder be electrified; the two balls will at once diverge. If whilst in this condition the ribbon be unrolled, we shall see that the balls fall together because the density of the charge and

also its potential decreases. This results from having the same quantity of electricity on a much larger surface.

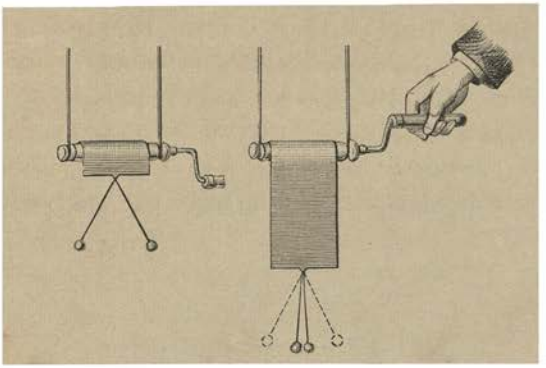

FIG. 90.—Experiment on the distribution of electric charge.

A similar experiment consists in placing a length of chain on the disc of a gold leaf electroscope (Fig. 91); if the electroscope be now

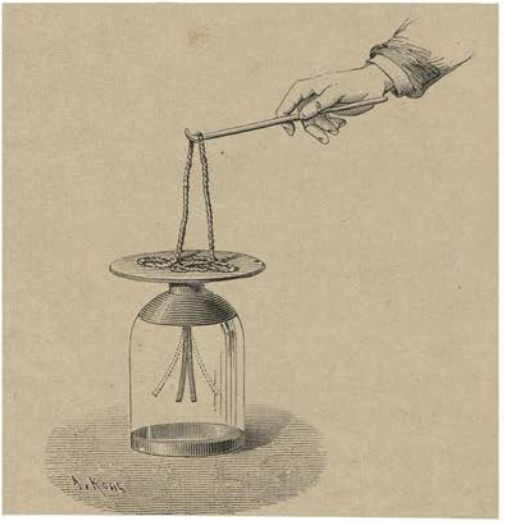

FIG. 91.—Experiment on distribution of charge.

charged by means of a rod of glass or resin, the leaves diverge. Let the chain be then lifted by an insulating rod; as the chain is raised,

the leaves fall together, owing to the decrease of potential with the increase of surface.

A hollow metallic sphere, provided with a hole in the top, is supported on an insulating stand (Fig. 92). It is now charged with electricity. In order to determine the distribution of electricity, we employ a small piece of gilt paper fastened to the end of an insulating handle, and called a *proof plane*. This proof plane is touched against any exterior part of the sphere, and then held towards the pith ball of an electroscopic pendulum, which is attracted. The proof plane is

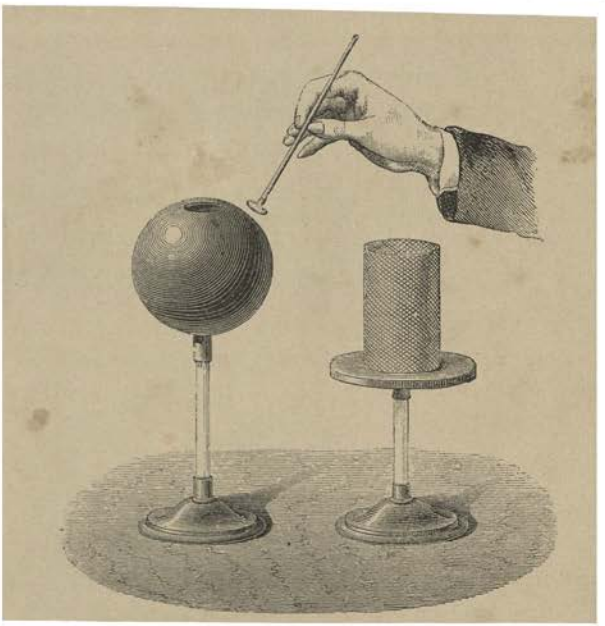

FIG. 92.—Distribution of charge on a hollow sphere, and on a wire-gauze vessel.

now touched by the hand to discharge it; now, on applying the proof plane to the interior of the sphere, and again testing it, we can get no signs of electricity at all. We obtain the same result if we begin with the interior of the sphere. Faraday tried the same experiment, only he used a cylinder of gauze placed on an insulated plate of brass (Fig. 92). He then electrified the plate of brass, and examined the distribution of electricity over the whole. He found it was all on the exterior, but none on the interior. Another experiment, due to Faraday, known as the butterfly-net experiment, is made with

a long conical gauze net, attached to a ring on an insulated handle. The net is electrified, and the electricity is found to be entirely on the exterior surface. While still insulated the net is turned inside out by the aid of two silk strings attached to the apex of the cone, when the electricity is again all found to be on the outside, there not being any on the inside (Fig. 93).[1]

Faraday has left the record of a series of curious experiments, proving that a charge of electricity on the outside of a body exercises no electrical effect at points in the interior space of the body. He inclosed a gold leaf electroscope in a case of thin metal, and found that it was not affected when the case was charged by means of a

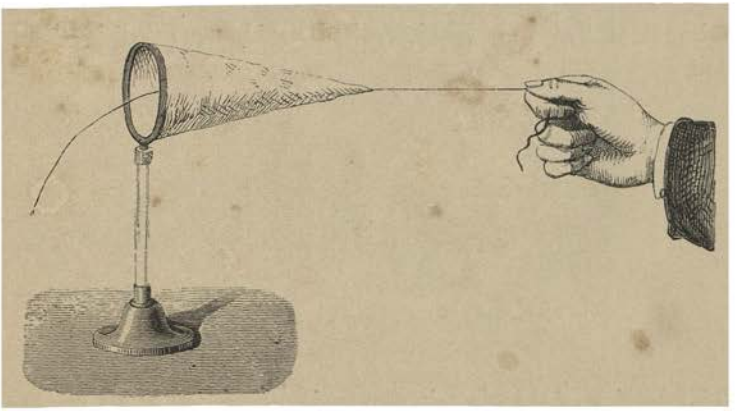

FIG. 93.—Faraday's experiment with the gauze net.

powerful machine. He found the same effect when he used a wire-gauze cage. Faraday constructed a cubical chamber, whose sides were twelve feet long, covered with metallic foil and wire netting, and was carefully insulated from the ground. It was then electrified. He himself went inside, and "lived in it," and tested it with delicate instruments. He had the room electrified so that large sparks were drawn from the outside and luminous brushes appeared at all points; he, however, felt no change, nor any of the sensations of being electrified, and neither did his electroscopes show the least sign of electrification inside.

Here we have direct proof that the stationary charge of electricity

[1] *Experimental Researches*, vol. i. paragraph 1173.

on a conductor is on its outer surface, existing apparently in a layer of an inappreciably small thinness. As a further proof, let us take two equal spheres, one of solid metal, the other of shellac, covered with gold leaf. Let the first be electrified, and its electrical[1] density or charge be taken with an electrometer. Now, if the two spheres be touched, they will each be found to have half the density possessed by the first one before touching. This shows that the layer certainly extends no deeper than the thickness of gold leaf. Indeed, there is no disproof yet made of the proposition that the charge resides outside the surface of the conductor; that, in fact, it is the air-surface, not the metal, that is really the seat of the charge. This is indeed the modern view, and it is strikingly confirmed by an experiment of Franklin's, which will be duly narrated in the next section.

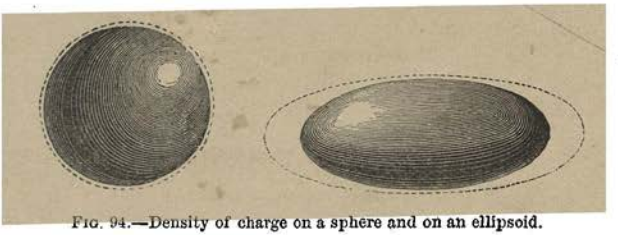

FIG. 94.—Density of charge on a sphere and on an ellipsoid.

The density of the electric charge is not equal at all points on a conductor of any other shape than a sphere. In the case of an elongated ellipsoid the density is greatest at the ends.

An attempt is made to illustrate this in Fig. 94, where the distance of the dotted line from the surface of the conductor is supposed to represent the density of the charge, that is to say, at the extremities of the long axis; in an oblate or flattened ellipsoid it is a maximum all round the circumference of the equator.

[1] Mascart remarks that it is better to use here the term, "electric density," instead of "tension," to express "the limit of the ratio of the quantity of electricity, which is spread on a small surface, including the point considered, to the area of that element of surface." In short, the word tension is used in electricity, with other meanings; for example, to express the pressure that an element of surface exercises on the surrounding medium; in that case the tension is proportional to the square of the electrical density, as we have just defined it. It has another meaning when used in connection with electric currents. Being an ambiguous term it is better therefore to avoid using it at all.

In a flat disc the electrical density is small and practically uniform all over the central region, but it increases towards the edges, where it becomes very great; in a cylindrical conductor with hemispherical ends the density is small, but uniform, all over the cylindrical part, until near the ends, where it begins to increase, and is greatest at the extremities of the axis. We see then how greatly the shape of a body affects the distribution of electricity over its surface. In every kind of form the densities are greatest at edges, sharp ridges, and acute points, or spikes. On these parts the density becomes sufficiently great to allow the electricity to fly off into the surrounding air, being really carried away by the air particles. This peculiar property possessed by points of producing a discharge was discovered by Mr. Thomas Hopkinson, a friend of Benjamin Franklin, more than a century ago.[1]

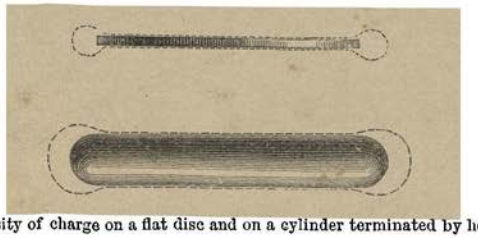

FIG. 95.—Density of charge on a flat disc and on a cylinder terminated by hemispheres.

The following quotation describes Franklin's own experiments on this subject:—

"Place an iron shot of three or four inches diameter on the mouth of a clean dry glass bottle. By a fine silken thread from the ceiling, right over the mouth of the bottle, suspend a small cork-ball, about the bigness of a marble; the thread of such a length as that the cork ball may rest against the side of the shot. Electrify the shot, and the ball will be repelled to the distance of four or five inches, more or less, according to the quantity of electricity. When in this state, if you present to the shot the point of a long, slender, sharp bodkin, at six or eight inches distance, the repellency is instantly destroyed, and

[1] In a letter written by this celebrated American to P. Collinson, and dated July 11th, 1747, several experiments are described to show "the wonderful effect of pointed bodies, both in drawing off and throwing off the electrical fire." It is on this power of points that Franklin based his first ideas of lightning conductors two years later.

the cork flies to the shot. A blunt body must be brought within an inch, and draw a spark to produce the same effect. To prove that the electrical fire is *drawn off* by the point, if you take the blade of the bodkin out of the wooden handle, and fix it in a stick of sealing-wax, and then present it at the distance aforesaid, or if you bring it very near, no such effect follows; but sliding one finger along the wax till you touch the blade, and the ball flies to the shot immediately. If you present the point in the dark, you will see, sometimes at a foot distance and more, a light gather upon it, like that of a firefly, or glowworm; the less sharp the point, the nearer must you bring it to observe the light; and at whatever distance you see the light, you may draw off the electrical fire, and destroy the repellency. If

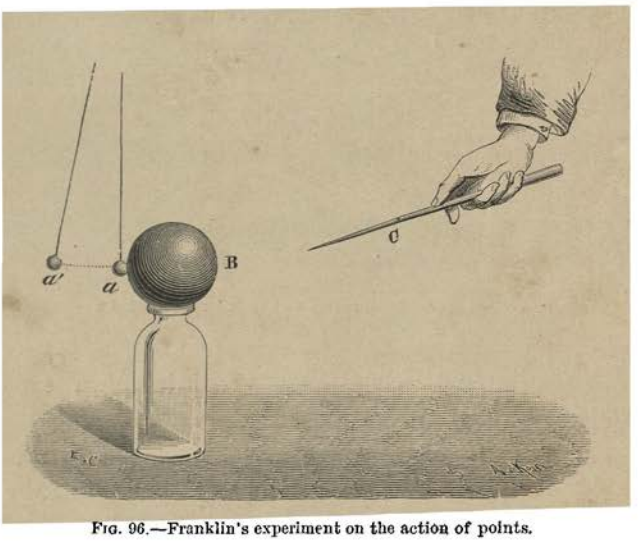

FIG. 96.—Franklin's experiment on the action of points.

a cork ball so suspended be repelled by the tube, and a point be presented quick to it, 'tis surprising to see how suddenly it flies back to the tube. Points of wood will do near as well as those of iron, provided the wood is not dry; for perfectly dry wood will no more conduct electricity than sealing wax."—(B. Franklin, *Experiments and Observations on Electricity, made at Philadelphia*, 1774, p. 3.)

It is calculated that the density of electricity at an infinitesimally fine point would be infinitely great; since it is impossible to charge a pointed conductor in the air with electricity; this is proved by

experiment. As fast as electrification is produced, it is given off the point into the air and disappears. When we examine the extremity of a point in the dark, there is seen a luminous crest, the shape and colour of which we will study further on. If, while the point is in communication with the source of electrification, one places one's hand before it, a draught is at once perceptible, arising from the motions of the particles of air. This can be still better shown by holding a candle-flame in front of a long pointed conductor. The electric wind is sufficient to bend the flame sharply down, or even to put it

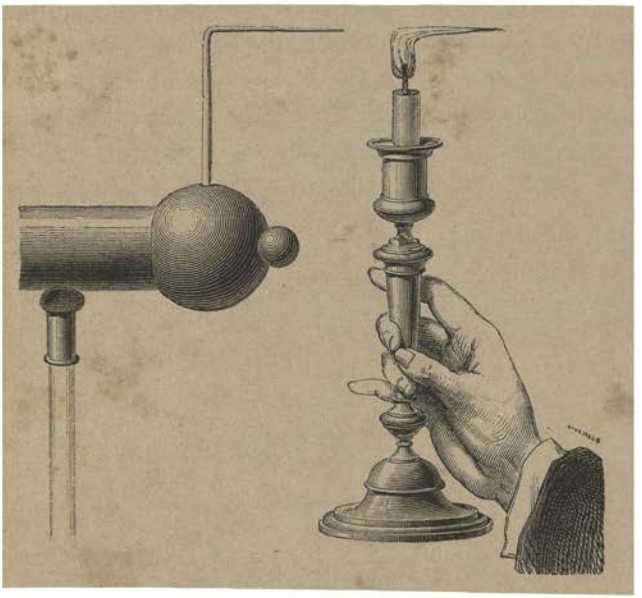

FIG. 97.—Action of points: electric wind.

out. This movement of the air at the points on electrified conductors has always been attributed to the accumulation of electricity, which has been compared to a fluid; but the following explanation seems to us preferable, as it involves no hypothesis on the nature of electricity, and besides, it is found to agree with known phenomena. The molecules of air, in contact with a point, electrified to a great electric density, become charged with the same electrification as the conductor itself. Hence the nearest molecules are repelled and others fill their place, which become electrified in their turn, and so on. Hence the current of air, which only lasts as long as the

electricity is being supplied. It can be stopped by putting a cap of sealing wax over the point.

The force of the air leaving the point, gives a counter push to the point in the opposite way, and if this point does not move it is because it is fixed. The existence of this reaction is shown by a small instrument known as an *electric whirl.* On a metallic support, a set of five or six pointed wires, diverging star-wise, arranged in a horizontal position, diverge from the central cap, which allows the whole to rotate round a pivot, in a horizontal plane. Each arm is bent back near the sharp point.

Hence when the whirl is placed in connection with a machine, and is electrified, it moves round in the opposite way to that in which the spikes point.

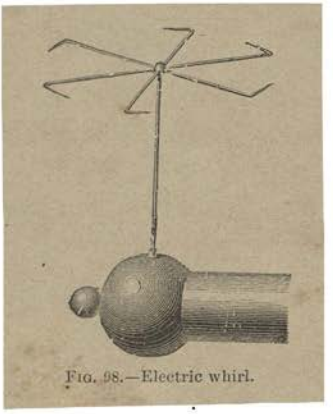

FIG. 98.—Electric whirl.

In the previous section we described the experiments of Coulomb which lead him to state the famous law of inverse squares. The experimental proof is delicate and difficult, for with whatever care one proceeds crude results only can be obtained, as errors are inevitable, and the law can only be approximately verified. It is interesting to know, that the law of inverse squares is indirectly proved by the distribution of electricity over the surface of bodies. The facts that we have just described, in this paragraph, are all explained by the hypothesis that the law of the inverse square of the distances holds good. When Newton showed that this was the law of gravity, his proof implied that an electrified spherical envelope can have no effect on any point in its interior. In the same way the whole of an electrified sphere acts on an exterior point as if all the

repulsive actions were united at its centre. On this hypothesis, if we consider an electrified body as made up of a series of concentric spheres, infinitely thin, the electrified particles on one shell will not be affected by the electrified particles of the shell next outwards, whilst they will be repelled by the inner shells. Any electrification will then be forced from the centre, outwards, until it comes to the outside, where the surrounding medium, if a bad conductor, retains it at the surface. This is as far as experiment takes us. Any other hypothesis which we might make on the law of the variation of electric actions with the distance would be incompatible, with the actual facts about the distribution of the charge on the surfaces of conductors.

The confirmation which the facts of the distribution of electricity thus give to the law of inverse squares becomes of greater interest than would seem at first sight to be the case; for the same mathematic law which is thus demonstrated to be true for electrical attraction is also the mathematical law of the attraction of universal gravitation.

CHAPTER III.

INFLUENCE, OR ELECTRICAL INDUCTION.

§ 1.—*Phenomena of Electric Influence.—Electrification by Influence.*

WE have just seen that there are two ways of electrifying a body, by rubbing, or by contact with a previously electrified body. The phenomena that we shall now describe constitutes a third method.

Let us take for example (Fig. 99) an electrified body C, in this case a metallic sphere mounted on a glass stem, and let us place near to it a conducting cylinder A B of considerable length, the ends of which are rounded, and the diameter of which is less than that of the electrified sphere. The conductor A B is also insulated either by a glass stem or by silk threads steeped in paraffin or varnish, which suspend it; at first it is unelectrified. As soon as the two bodies are brought near together the conductor shows signs of electrification. It is easy to prove this by bringing a pith ball pendulum near to one end, and observing how it is attracted to the conductor; or better still by observing two little pendulums, *a*, *b*, attached to the conductor, these little balls become electrified with the same electricity as the point where they touched and are therefore repelled. The method of electrification by bringing an electrified body near an unelectrified one is called *influence* or, *electrification by induction*.

The first phenomena of electrical influence observed were the attraction of light bodies by amber, that is to say the first and oldest experiments in electricity; we shall see that the attracted bodies become electrified as soon as the rubbed amber is brought near

enough to them: in fact, they are attracted because of the charges induced in them in this way, at a distance, without contact.

It was only in the middle of the last century that the real meaning of these phenomena was understood. Gray had already observed that an insulated cord was electrified by bringing a glass rod near to it but without touching it; previously, Otto von Guericke had observed that silk strings that hung near the ball of sulphur of his machine were repelled if he held his finger near to them even though none of them had touched the ball of sulphur. But neither of them understood the importance of these facts. The first explanation of these phenomena is due to John Canton, of Stroud (1753). Aepinus, some years later, showed the electrification of various parts of a body acted upon by influence.

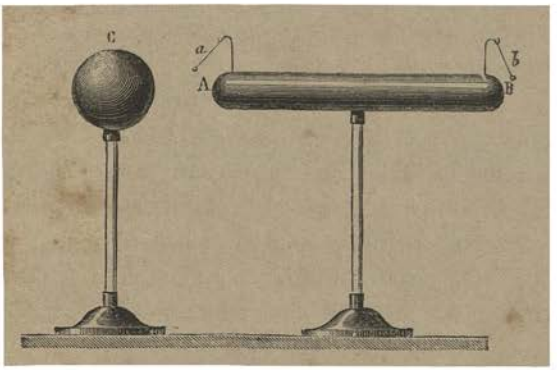

FIG. 99.—Electrification by influence.

We will now describe the electrification of a body when acted upon by influence. If the sphere C (Fig. 100) be charged with a *positive* charge of electricity the end A of the cylinder, which is nearest to the sphere will be charged *negatively*, the other end B will be charged *positively*. We can prove this if we bring an electrified pendulum near to each end in turn, suppose the little ball be charged positively, it is found to be attracted to the end A, when brought carefully towards it, but when brought towards the end B it is repelled. The reverse would be the case if the sphere C were charged negatively.

To study the distribution of the charges of electricity on the cylinder, we may attach at various parts little double pendulums

made with conducting thread (linen), and observe the divergence of the balls (Fig. 100). The greatest density is at each end and gradually decreases toward the centre M, where there is none, and for this reason the middle part is called the *neutral* zone. The zone of the cylinder that is unelectrified is slightly nearer the end of the cylinder A than it is to B, and is not quite at the middle of the conductor when electrified by influence. This is due to the density of the electricity at A being somewhat greater than it is at B.

Whilst the arrangement is electrified let us move the sphere away, the little balls of each pair will then gradually approach one another until when at a sufficient distance away they touch each other; showing the sphere is too far away to affect the cylinder.

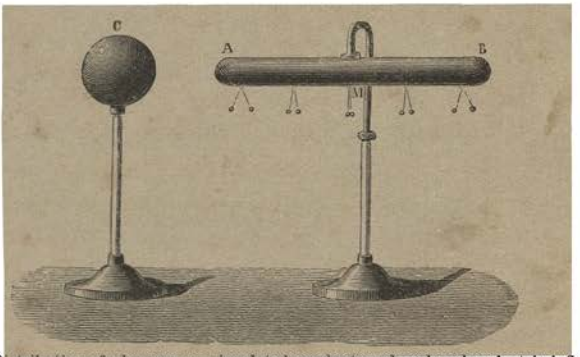

FIG. 100.—Distribution of charge on an insulated conductor placed under electric influence.

The same effect would be produced if instead of moving the sphere it be touched with the hand and so discharged.

When the electrified sphere is brought near the cylinder it is found that there is a reaction of the cylinder on the sphere, and that the distribution of its electricity is disturbed by the pressure of the induced charge at A; the effect being to increase the density on the side nearest the cylinder and to diminish it on the side furthest removed.

This may be proved by touching the two sides with a proof plane and examining with the electroscope.

In the experiment just described the influenced conductor was insulated. Suppose we now bring the inducing or influencing sphere into the neighbourhood of the conductor and connect the far end B with the earth. In this case the charge at B is repelled off to the

earth, leaving the whole of the long conductor electrified with an induced charge of opposite sign to that of the charge on the inducing body. This induced charge is strongest at A, and diminishes in density all along toward B; but the neutral zone observed before the conductor was put in communication with the earth will be found now to have disappeared.

The nature of the remaining charge, its distribution on the conductor, or its density at various points, would remain the same if any other part of the cylinder had been put to earth, even the end A. If, after having made connexion with the earth, that connexion is again broken, everything will remain in the same state; that is to say, so long as the inducing sphere remains to exercise its influence,

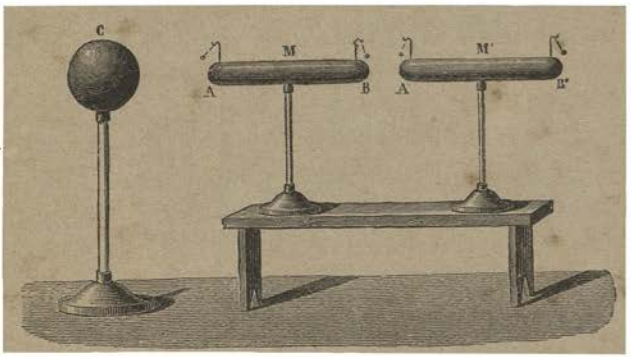

FIG. 101.—Electrification by influence of a series of conductors.

so long will the conductor remain charged with the opposite kind of charge to that of the inducing sphere, but unequally distributed. If the sphere be removed, the induced electricity remains on the surface of the conductor only; it will now spread itself symmetrically over the two ends; and we have here a body electrified *by influence*, charged with electricity as if it had been directly charged by friction or by contact.

When a series of conductors A B, A′ B′ &c. (Fig. 101), instead of only one conductor, are brought into the presence of an electrified body, we find that they are all electrified at the same time; but the density of the successive charges decreases with the distance from the sphere, the conductor A′ B′ would be less influenced than it is, if the conductor A B be removed, showing that the inductive effect is

not all due to the charge on the sphere, but that each conductor influences the next.

The preceding facts are very important.

[Formerly it was sought to explain them by the hypothesis of the two electric fluids each of which repelled itself but attracted the other. The modern rational way of regarding the matter is as follows: the two electric states called the "positive" and "negative" merely signify that the body in that state has either a surplus or else a deficit of electricity relatively to the things around it. Everything is regarded as being always electrified up to a certain degree; if everything were *equally* electrified there would be no electric phenomena. Electric phenomena only occur when the uniform distribution is disturbed. If to any conducting body we add a surplus of electricity, that surplus at once tries to spread in all directions. If from any conducting body we take away some electricity, leaving it negatively charged, then its deficit also tries to spread, and the electricity of outside things tries to fill up the deficit; and in all neighbouring conductors there is a rush of electricity toward the negatively charged body. Similarly in all conductors near to a positively charged (surplus) body, there is a rush of electricity away from the surplus, so that the parts of those conductors that are nearest to the surplus are left in a negative state of charge. According to this view there is no real "attraction" between positive and negative charges. The negative charge is apparently attracted toward the positive, but only apparently, for the negative charge is due to the electricity being *repelled* away by the neighbouring surplus charge.

On this view that an unelectrified body contains neither more nor less electricity in proportion than all the things around it, we have now to examine some of the other facts. When we rub two things together—say a piece of glass and a piece of silk—what we do disturbs their electric equality of state, the friction of their molecules at the surface rubs some electricity out of the silk, leaving it negative, into the glass making it positive. It is self-evident that on this way of viewing matters, the surplus gained by the glass is equal to the deficit on the silk. This most simple fact used to be explained formerly in the most cumbrous way by saying that a certain quantity of a positive electric fluid, and an exactly equal quantity of a negative electric fluid were separated or generated by the act of rubbing.

On the modern view, electrification by influence is equally easy to explain. There is, in our fundamental experiment, an electrified sphere brought into the presence of a non-electrified, insulated, long-shaped conductor. Non-electrified of course means that it is not either under-charged or over-charged as compared with the air around it and the earth beneath it. Suppose the sphere to have a surplus or positive charge, then when it is brought near to the long conductor the tendency for the electricity of the whole system to rearrange itself by mutual repulsion produces the following effect. The electricity of the long conductor is pushed away from the surplus of the sphere, and retreats somewhat, leaving the end nearest to the sphere under-charged or negative, and the end furthest from the sphere becomes over-charged or positive.

Now take the other case where the influencing sphere is brought in negatively charged. Owing to the mutual repulsion between all electric particles there is a tendency for electricity to flow from the place where there is "more" to the place where there is "less," and so to restore uniform distribution. So when the negatively charged sphere is brought into the presence of the long conductor, its effect is to influence the distribution of the electricity of the long conductor which previously was neutral with neither surplus nor deficit. The electricity of the long-conductor can no longer remain undisturbed, there is a tendency for it to be impelled towards the neighbouring deficit, and some of it rushes in that direction, heaping itself upon the near end in a positive charge, and leaving the far end in a state of negative charge. Of course somewhere along the conductor, between the surplus at one end and the deficit at the other, there will be a part where there is neither surplus nor deficit, and this is what was called the neutral zone. Again, when any point of the long conductor is connected by a wire to the ground, the long conductor and the earth become, for electrical purposes, one single big conductor. Under the influence of the neighbouring charged sphere, the neutral zone will now be much farther away, the earth being relatively immense.

Again, we may apply the same order of ideas in explaining the attraction of non-electrified bodies by electrified ones. When a rubbed glass rod C (Fig. 102) is brought near the pith ball used as an electric pendulum, what is it that happens? Pith is a conductor

of electricity, though a poor one. Under the influence of the neighbouring positive charge, its own natural electricity which it has in the so-called "uncharged" state is repelled on one side or displaced within it, leaving it negative at *a* and making it positive at *b*. Now comes in the law of inverse squares. The positive charge at *b* is repelled by the positive charge of C, but feebly, owing to the distance between them. The portion of *a* which is negatively charged and near, is (apparently) attracted, and is at a shorter distance. Hence, though the charges at *a* and *b* are equal, the forces are not, and the attraction is the greater. This we may still further analyse. The charge at *b* being a surplus, the repelling force at that point due to C is a little more than if there were no surplus there, or is a little more than if ordinary air were at that point. The charge at *a* being a deficit, and near to C, the repulsion at that point due to C is a good deal less than if ordinary air (or any other non-electrified medium)

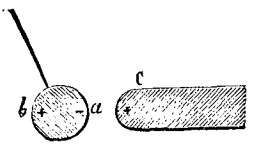

FIG. 102.—Cause of electric attraction.

were at that point. Hence, since on the whole there is less repulsion exercised on the ball than on the medium surrounding it, it moves up towards the rubbed glass rod as if it were attracted. Is this explanation hard to understand? Take an inverse example of a familiar nature. A balloon rises, apparently repelled from the earth. It is not really repelled, but attracted: yet it rises apparently against gravitation. The explanation is that though it is attracted by the earth it is less attracted on the whole than the masses of air which surround it, and which therefore displace it.

Electric influence also comes in in the communication of electricity by contact. A charged body when made to touch against another uncharged body, shares its charge with the latter, a spark passing between them just before they touch. At the instant before the spark passed, when they were quite close together, one was under the influence of the other, and a displacement had already taken place in the uncharged body exactly as it did in the long conductor or in the

pith ball. Then followed a momentary rush (in a spark) of charge between the two nearest surfaces, the surplus of one rushing over to fill up the neighbouring deficit.

Lastly, the action of points, briefly alluded to above, is a phenomenon of influence. Even at a considerable distance the spiked conductor, bodkin, or whatever it may be, was acted upon by the presence of the neighbouring charged body, and either a surplus, or a

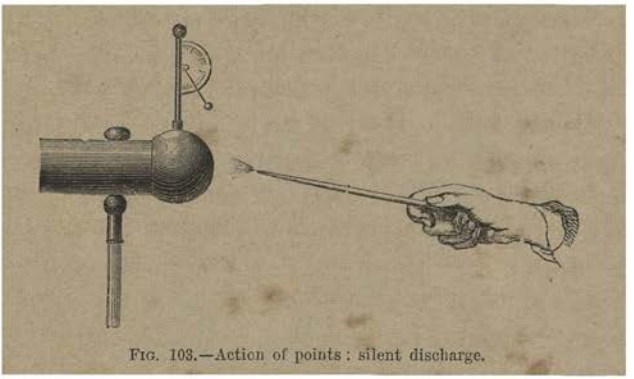

FIG. 103.—Action of points: silent discharge.

deficit (according to whether the influencing body was charged negatively or positively to begin with) accumulates in great density at the tip of the spike, and is communicated to the nearest air-particles which fly off by repulsion, and neutralise the opposing charge on the opposite surface.]

§ 2.—*The Phenomena of Electric Influence through Bad Conductors.*

THE ELECTROPHORUS.

In the preceding paragraphs, it has been always assumed that the body influenced was a conductor, such as metal. The phenomena would be the same if the influenced body be a poor conductor; only the displacement and flow of electricity from one end to the other of the influenced body might take place a little less instantaneously.

If we take a substance which is so bad a conductor as to be an insulator, for example a ball of wax, and expose it to the influence of

a charged body, there will be no such rush of electricity through it, its nearest surface will not be found—at any rate after the lapse even of many hours—to be electrically either positive or negative as compared with its further surface.

Nevertheless, it will be found that insulating bodies such as wax, shellac, glass, ebonite, air, oil, turpentine, &c., though they do not themselves become electrified by influence, all allow the action called influence to operate through them upon conducting bodies placed beyond them. If a conductor is hung in oil or turpentine by silk strings, and then a charged body is brought near, the conductor will be found to be influenced across the intervening oil or turpentine exactly as it was influenced across the intervening air, only with this difference, that the presence of oil or turpentine as the medium instead of air appears to promote and assist this action which we call influence or induction. Also, if a glass plate, or a slab of wax or sulphur, or a sheet of gutta percha or of india rubber, be placed between the inducing charged body and the conductor, the action called influence will go on as before, the presence of the glass, wax or other material assisting instead of stopping the effect. We shall come back to this matter in Chapter V. when we discuss the Leyden jar and the properties of "di-electrics" in general. But we must now assume that in the air and in all the insulating bodies, such as glass, wax, resin, this same property of allowing influence to go on across them exists. If it were not so we could not have the useful instrument which we are about to describe under the name of the *electrophorus*.

This instrument is due to Volta, who gave it the name of the "perpetual electrophorus" because it preserves for a long time the charges that it has received.

It consists of two parts; a cake of insulating material, AA (Fig. 104) such as resin, sulphur or india-rubber, cast into a wooden or metal tray, CC; and a metal disc, BB, fixed to an insulating handle of glass, or to silk cords. Frequently the disc BB is of smaller diameter than the cake, and sometimes it is made not of metal but of wood, covered on both edge and faces with tin foil.

To use the electrophorus, remove the metal disc and rub the insulating cake with flannel, woollen cloth, or fur, best of all with a cat skin. This produces negative electrification on the resinous cake. This you may prove if you bring your finger near the cake, for you

will observe small sparks and crackling sounds. Now take the metal disc by the insulating handle, and place it on the rubbed insulating cake.

Now pause a moment: let us think what has happened in this action. While you were putting down the lid on the cake, even before it touched the cake, it was under influence. The cake is negative, hence as you hold the lid over it there will be a displacement and a rush of electricity in the lid, causing a positive charge to accumulate on the lower side, leaving the upper side negative. This effect will of course increase as the disc is lowered; see Fig. 104, where the + and — signs indicate the state of things. It will be noticed that the metal dish in which the cake stands is also under influence: but this is of no importance to us.

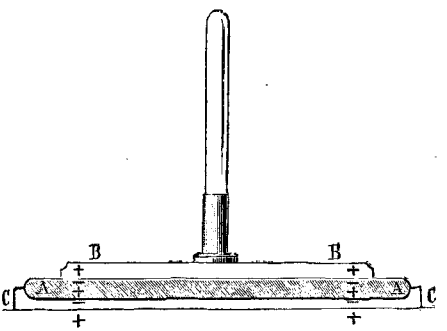

FIG. 104.—Electrophorus.

You must now touch with your finger (Fig. 105) the top of the lid. Your finger will also be under influence during this action; a + charge accumulating on its tip, and then discharging itself with a small spark to fill up and neutralise the — charge on the top surface. Now lift up the lid by the handle. You will find that it is positively electrified, and you can carry away the charge and use it to give a big spark to any other conductor. You can then put the lid down again on the cake, touch it, lift it up again and take another spark as often as you please, the cake remaining all the time charged with its original charge.

The length of spark is roughly proportional to the size of the electrophorus.

Mascart in his treatise says that Lichtenberg constructed an electrophorus with a cake six feet across and the disc was five feet across and the sparks drawn from it fourteen to sixteen inches long. Another very large electrophorus was made by Kleindworth for the University of Göttingen the cake of resin was 2·25 metres in diameter and the conducting disc 2 metres.

FIG. 105.—Management of the electrophorus.

The cake sometimes preserves its charge for months, if it be kept in a cupboard where the air is perfectly dry.

We have said that the insulating cake of the electrophorus is made of resin, sulphur or india-rubber. All good insulators can be used; mixtures of these substances are generally used in order to make the cake less brittle.

There were, in the Italian section of the International Electrical Exhibition at Paris, two electrophori, one was made of fine sealing

wax, the other of a mixture of 3 parts of turpentine, 2 parts of resin and one part of wax with a little colouring matter.

The following is a mixture frequently employed:—

Resin	25 parts.
Venice turpentine . . .	5 „
Shellac	70 „
Total . . .	100

Many electrophori are made of ebonite or hard black india-rubber; but these cakes are liable to be affected by the moisture of the air and they also warp.

The electrophorus is a very convenient instrument as it is always ready, one slight operation exciting it into activity. In using it, certain precautions that we shall now name must not be neglected.

If we place the metal disc on it and again withdraw it without having touched it or put it in connection with the earth, it will be found to be unelectrified. This is because, if we do not touch the top the + and — charges on the lower and upper sides of the lid will neutralise one another directly the lid is lifted up out of the influence of the cake. To get a charge by this inductive process, the thing that is being used, whether lid or ball, must be *touched while under influence*. Of course the touching may be done by a wire. In some forms of instrument a metal pin strikes up through the cake to touch the lid from below. In others a strip of tinfoil is stuck down with varnish across the top of the cake.

Another curious phenomena is this: that if the metallic tray or sole of the cake be insulated, the apparatus will no longer work, or at the best will give very weak results. This is explained by the fact that, by exciting the upper face of the cake negatively, we induce a positive charge on the upper face of the metal dish.

Care should be taken that the cake is kept dry. The flannel or fur should also be warm and dry, and the handle of the lid must be scrupulously clean and dry.

The phenomena of electrical influence or induction bear a remarkable analogy to the phenomena of magnetic induction, which we described in Book I. A series of conductors one after the other

in the presence of an electrified body is similar to a series of magnetic elements whose poles all arrange themselves in the same direction, so that contrary poles are turned towards each other. The conductors in the series we have described are affected by the two opposite electrifications, or, if we prefer it, they are electrically "polarised" in the same way. This electric state is temporary, as the magnetic state is in soft iron, and disappears as soon as the electrifying body is removed.

This polarisation takes place from molecule to molecule in all electrified bodies, either good or bad conductors; but there is this great difference between the two kinds of bodies: whilst in a good conductor, the charges pass from one to the other molecule with great rapidity and ease; by a series of successive discharges in truly insulating substances there is no discharge from molecule to molecule, though the molecules themselves are under influence. Maxwell calls the propagation of influence across an insulating body "displacement" as distinguished from the "flow" of electricity which occurs in a conducting body.

Various experiments have been designed to show the electric polarisation of molecules in a non-conductor. In a small glass trough, C, filled with turpentine, some small pieces of silk threads are placed. Through a hole at either end of the trough enter metal rods, A and B, terminated in points and opposite to each other. One of the rods A is connected with a source of electricity, the other one, B, is put into connection with the earth by a wire or chain. As soon as the rods are electrified the particles of floating matter arrange themselves in a quivering line between the ends of the metal rods. This electric chain has a certain power of resistance, for, if we disturb it by the aid of a glass rod, the particles at once begin to put themselves in order, again showing that it is the polarised state of the molecules of liquid that holds the particles in their places. If, now, in the place of silk we put small particles of a conductor, we observe a series of sparks jumping across from particle to particle all along the chain. This experiment (Fig. 106) is due to Faraday.

Matteucci, having electrified a bundle of very thin mica plates, which he then dismounted, handling them in glass pincers, found each plate to be electrified positively on one side and negatively on the other, the intensity decreasing from the exterior inwards to the middle. A

similar experiment was made by Buff with a number of thin discs of resin.

These latter experiments, besides showing the distribution of electricity in insulating media, prove also that electric influence acts right through them. The depth of the penetration of the effect can be tested in the following way. A candle is taken and stuck on to an electric machine: the end becomes charged positively. The candle is now taken off, and the end is touched either by the hand or with a metal disc, or the end is just melted. After some time the end of the candle which was rendered neutral again becomes charged with a positive electrification. This charge evidently comes from a gradual relaxing of the state of the interior electric stress which had remained after the candle was removed. Matteucci has made some very interesting researches of the pentration of electricity into the interior of insulators. For this purpose he used cubes of spermaceti.

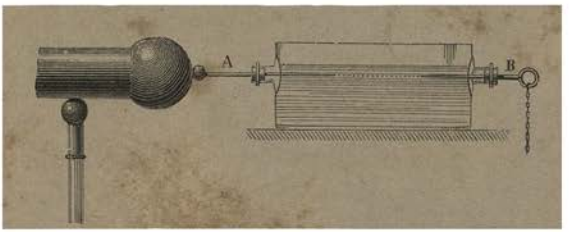

FIG. 106.—Faraday's experiment on the polarisation of particles in a di-electric medium.

Whenever we have a medium, whether air, or turpentine, or glass, acting as the agent for this electric influence, we must consider the medium itself as taking the chief part in the action. If we have a positive charge on a conductor at one side of a layer of air, turpentine, or glass, and a negative charge somewhere at the other side of the layer, the space between will be in the peculiar condition which was above expressed by the vague term "under polarisation," its particles, whether fixed (as in solids) or movable, (as in turpentine and air) being under a particular kind of stress. Faraday's pregnant experiment (Fig. 106) with the turpentine and silk enables us to get a graphic idea of the forces acting across such a medium, precisely as the iron filings in our magnetic experiments enabled us to get an idea of the invisible magnetic lines of force that lie in the space between a north magnetic pole and a south magnetic

pole. We must henceforth consider all the space between a positive charge and a negative charge of electricity, to be filled in the same way with invisible lines of electric force which curve round and pass across the medium. Kirchhoff and Maxwell have gone further, and introduced the idea of "tubes of force," each tube beginning at a unit of positive charge on one surface and ending at the opposite surface in a corresponding negative unit, the whole space between being mapped out into "tubes." We must also, henceforward, think of these insulating substances not as mere insulators or non-conducting bodies, but as possessing specific powers of their own to help this effect which we have called influence. It may be that two bodies that are equally good as insulators may differ in their power of helping or permitting influence to take place. Hence such bodies are now usually referred to as *di-electrics*. Flint glass, bisulphide of carbon, and gutta-percha are good di-electrics, having a high inductive capacity, whilst air and rock-salt, which when dry are equally good insulators, are not so good di-electrics, as they have not so high an inductive power.

§ 3.—*Lichtenberg's Figures.*

The property of bad conductors to retain for a long time a charge of electricity that may have been developed on their surface, may be shown in quite another way. Taking the resinous cake of an electrophorus, we may show some very curious experiments on the ways in which electricity spreads itself around points on the electrified insulator.

For example: if, after having raised the disc of the electrophorus with its positive charge, the edge of the disc be brought near the cake a spark will pass. The positive charge of the disc suddenly discharges itself into the surface of the cake at the point of contact; some of this charge is used in neutralising the negative charge around the spot, but some of it remains and spreads in a circular region of a certain size surrounding the point of contact. To show the existence of this electrified spot, a mixture of red lead and flowers of sulphur is taken and mixed well together, the mixture is then shaken through muslin over the electrified cake. Whilst passing through the muslin

sieve both become electrified, the sulphur negatively, the red lead positively. The sulphur is attracted, while falling, to the points on the surface electrified positively, and the red lead is attracted to the rest of the cake. The result is a yellow disc; a neutral black zone and the rest of the plate is red.

FIG. 107.—Lichtenberg's figures.

Figures and patterns can be obtained by tracing designs on the cake with the knob of a charged Leyden jar; or, if the cake is first highly charged, touching it with the finger is sufficient. These figures are called Lichtenberg's figures, from the Austrian physicist of that name who first discovered them. Figures 107, 108, and 109 are copies of figures made for us by M. Saint Edmé of the Conservatoire des Arts et Métiers. The marks forming the letter G (Fig. 107)

were made by the knob of the interior coat of a Leyden jar on a cake of resin; they show how the positive charge of electricity spreads on the surface of a bad conductor.

The exterior lines were made by taking the same Leyden jar by the knob, and tracing the lines with the edge of the bottom of the jar; this was done to compare the two kinds of marking; and it is found that negative charges of electricity give an entirely different distribution from positive. This difference is still more marked in

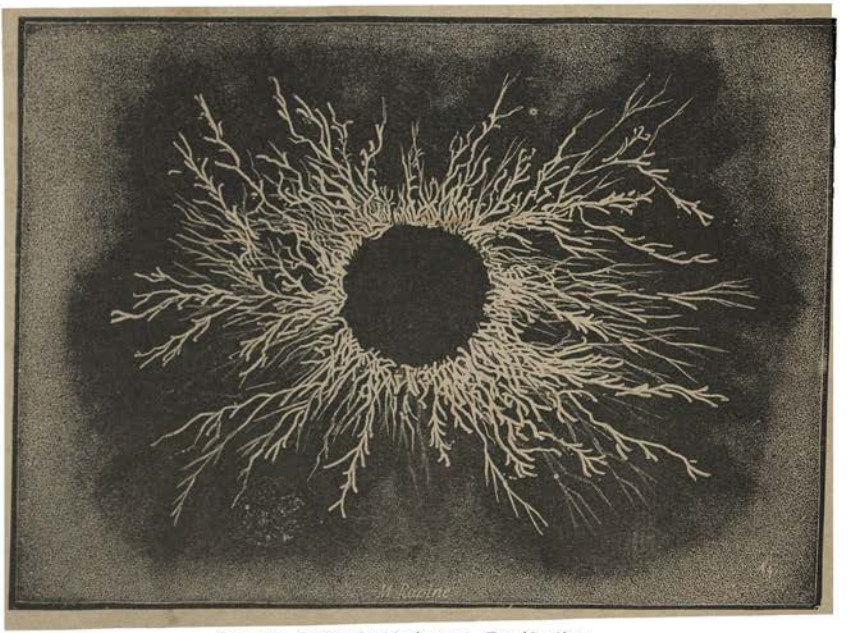

FIG. 108.—Lichtenberg's figures. Ramifications.

the figures drawn in Figs. 108 and 109, which show separately the two kinds on the cake of an electrophorus.

In the latter pattern, the negative charge is shown with its concentric rings and neutral spaces between them. An experiment due to Aepinus, based on Lichtenberg's figures, shows, in a striking way, equally the distribution of the two kinds of charges in alternate zones on bad conductors. He took a glass plate and brought one edge of it into contact with the conductor of an electric machine; he then allowed the plate to remain at rest for some time, after which

he found the plate charged in zones, the first was the positive, direct from the machine, then a negative, followed by a second positive zone: this was, of course, observed by sprinkling the powder, minium and sulphur, over the plate. He was able to observe six or seven alternating bands of yellow and red.

Lichtenberg varied his experiments of this kind in a hundred ways.

In one of these, after having strongly electrified the cake of the electrophorus, he placed on its surface a metal plate, which produced

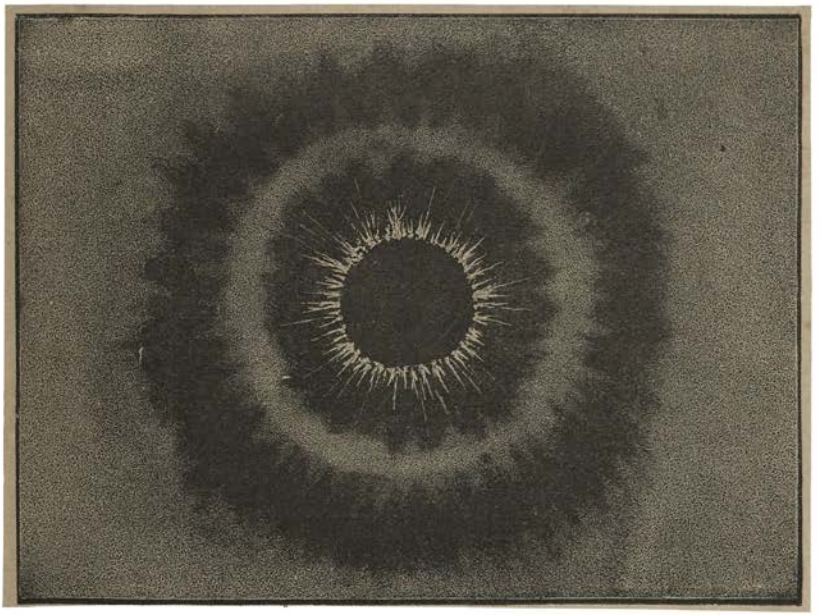

FIG. 109.—Lichtenberg's figures. Spread of negative electrification.

many small discharges and sparks. These discharges took place at points where there was contact between the two surfaces; the remainder being separated by a thin film of air. Then, after the disc had been removed, he sprinkled the mixed powder over the cake of the electrophorus, and then found that he obtained a number of yellow points, showing that the conductor had sparked to the cake at these points. If he waited longer before sprinkling he found that these points vanished, and the cake remained evenly charged with a

negative electrification. In conclusion, we have been able to distinguish between the two kinds of electrification, first by the difference in the action in the phenomena of attraction and repulsion, and secondly by the very different way in which they spread over the surface of bad conductors. This is the chief reason why Lichtenberg's experiments are so interesting.

CHAPTER IV.

ELECTRIC MACHINES.

§ 1.—*The First Electric Machines: Historical Sketch.*

AT the outset those physicists who originated the study of electrical phenomena were limited in making their experiments, to the primitive process of rubbing those bodies which they wished to electrify. At first they used sticks of resin or sealing wax, or glass tubes and the like. Then about the time of Franklin large tubes came into use, about three feet long, and from an inch to an inch and a half in diameter; these were rubbed either with a dry hand, or, if the hand became moist, by brown paper dried at the fire. Otto von Guericke conceived the idea of making a machine of a ball of sulphur cast on an axle, and which was turned by a winch. This ball, whilst being rapidly rotated, was rubbed by another person with the palms of his hands, the friction of which electrified the sulphur strongly. The experimenter then lifted the sphere by its spindle to use it for his experiments. Afterwards it was found that a chain might be hung over the globe to receive the charge from the sulphur ball. Sir Isaac Newton suggested the substitution of a glass globe. Later (1740), von Bose, a professor of physics at Wittemberg, substituted a globe of glass for the globe of sulphur, and improved the mechanism for rotation. The most important improvement brought out by this experimenter consisted in collecting the electricity developed by the glass. For this purpose he suspended a metal cylinder above the globe of his machine by silk strings. In order to collect the electricity from the globe, one end of the cylinder is brought very near the top of the globe, so that sparks could pass from the globe to the cylinder, which then remained charged with the same kind of electrification as is produced on the globe. Afterwards he employed

a metallic chain to conduct the electricity from the globe to the cylinder. This method of collecting is shown in Plate V. This form of machine is due to the Abbé Nollet in the middle of last century, and is simply Bose's machine modified.

How the improvements from that form of machine to those in use in the physical laboratories of the present day came about, we will now briefly describe. First, the shape of the body rubbed was modified: Watson employed four glass globes; Wilson, Cavallo, and Nairne used cylinders instead of spheres, Sigaud de la Fond, Le Roy, Cuthbertson, Van Marum, and Ramsden, used plates of glass instead of cylinders or globes. The advantage of this change is to allow of a larger surface being rubbed, and to reduce the speed of rotation.

Another improvement suggested by Winckler, of Erfurt, consisted in using cushions of wool or leather, covered with tinfoil, or with an amalgam of tin or zinc. At the present time either an amalgam of zinc, tin and mercury is employed, or else mosaic gold (sulphide of tin) is used, which is laid on with a very small portion of tallow. The friction then occurs between the amalgam and the glass.

In the early machines the electricity passed to the conductors by successive discharges seen as sparks, or by chains, or by strips of stuff joining the conductor to the insulated glass globes of the machine. Wilson was the first to use points in the way that Franklin had just discovered. The prime conductor of his machine was a metal cylinder terminated in knobs and held by silk strings. A metal rod projected downwards from the conductor to the glass cylinder, and held a metal comb towards it.

Such are the principal improvements in frictional machines since the time of Otto von Guericke to the present day. This short sketch will allow us the better to understand the present arrangements which we will now describe.

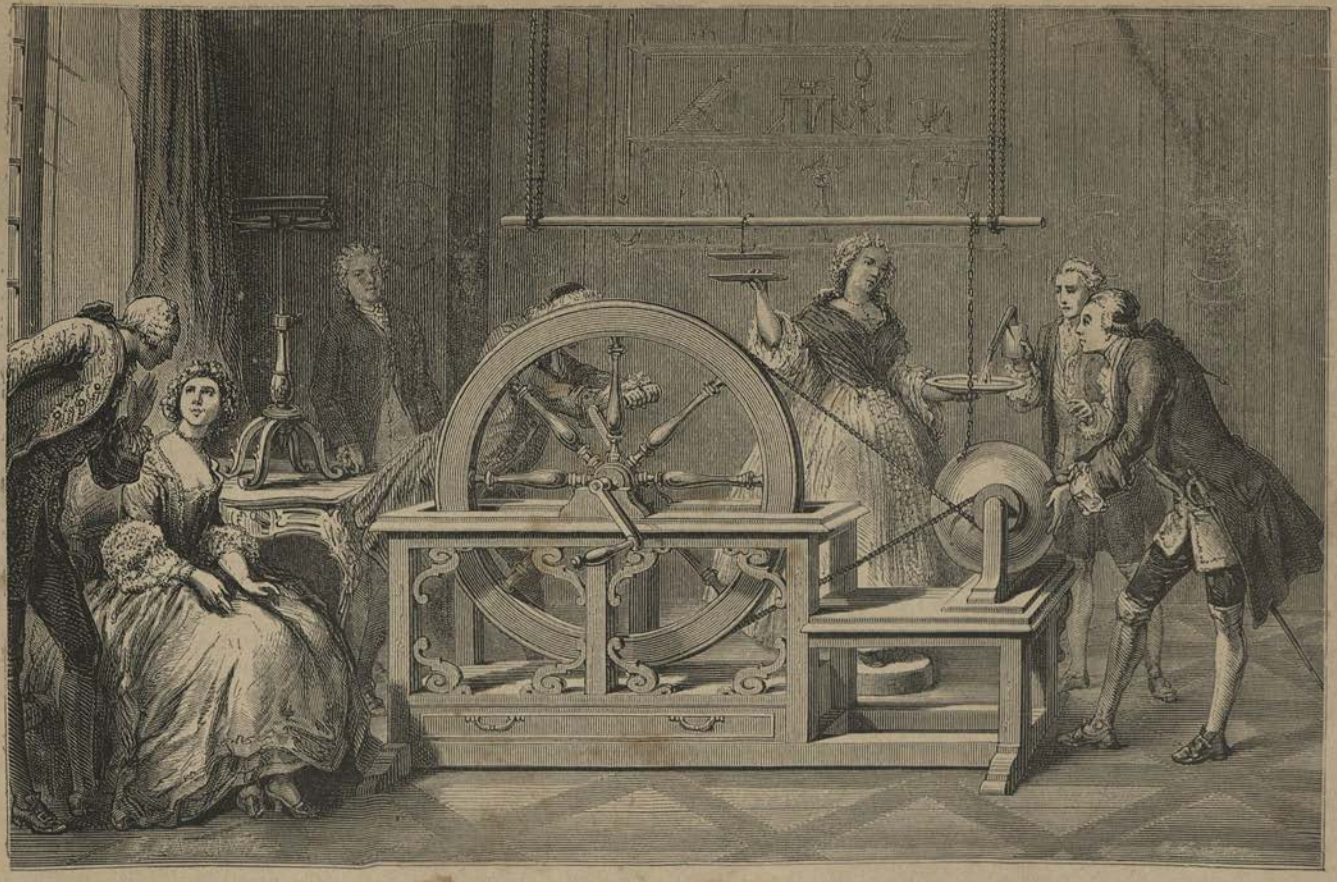

PLATE V.—ELECTRIC MACHINE WITH SULPHUR GLOBE; ACCORDING TO THE MODEL IN FASHION ABOUT 1754.

§ 2.—*Frictional Machines.*

An electrifying machine consists of the combination of two bodies, which when rubbed together produce electrification, and of a third body which acts as a collector for one or other of the two charges. The passage of the charge from either body to the collector is either by contact or by influence. Otto von Guericke's machine scarcely came within this definition, as it had no specific conductor. The electrophorus is a very simple kind of electric machine, and very convenient, having the distinct advantage that, for a long time after once having been rubbed a charge can be obtained from it without its being necessary to commence the operation each time.

The first machine we will describe is that known as Ramsden's machine, as shown in Plate VI.

A large circular plate of glass[1] is mounted vertically on a metal axle, about which it can easily be turned by means of a crank handle. Whilst passing between the two wooden supports, the surface of the glass is rubbed by two pairs of rubbers fixed to the supports. The rotation of the glass then causes it to become electrified positively on both faces. The negative charge of the rubbers is neutralised by being connected to the ground through the frame, which is not insulated. In other words, electricity runs up the frame to discharge itself into the rubbers. If the rubbers were insulated, a time must soon be reached when the influencing effect of their charge will be equal to their electrifying effect as rubbers, and the machine will cease to act; it is necessary, therefore, to keep the rubbers in conductive connection with the earth. Each rubber is stuffed with hair, and is covered with leather: on its

[1] Machines have been constructed with plates of sulphur. M. Richer has a note on this subject in the *Comptes Rendus de l'Académie des Sciences*, 1865. The choice of glass is not a matter of indifference. Electric instrument makers are agreed that the old plate glass with natural vitrefied surface was the best. It is said that the superiority consists in there being so little potash used in its manufacture: the surfaces being, for that reason, less hydroscopic. Olive-coloured bottle glass, cobalt blue glass, and flint glass, are equally good for this purpose. Whatever is the nature of the plate, it is necessary to clean it at times with alcohol, naphtha, or paraffin oil, to remove any matter left from the cushions.

surface is placed a quantity of mosaic gold, or an amalgam of mercury with zinc, bismuth, or tin.

Such is the arrangement of the parts for producing the electricity. Now let us examine the arrangements for collecting the charge. First, there are the *prime-conductors.* They consist of two long brass cylinders terminated at each end by knobs, and insulated by glass legs. These cylinders are connected to one another at their further extremity from the machine by a metal rod. The extremities of the conductors nearest the machine carry metallic combs bent round and brought with the points close to both faces of the glass plate, but not quite touching it. Now as to the action of the machine. The glass plate is charged positively by friction against the rubbers; whilst in this state it acts by influence on the conductors, repelling a positive charge to the ends of the conductors, and leaving negative the parts nearest to it, viz., the combs. The negative charge sets up a wind at the points of the combs, producing a continual discharge between the surface of the glass and the prime-conductors. The glass is continually being re-electrified positively by friction with the rubbers, thus causing an accumulation of electricity on the conductor. Upon one of the conductors it is usual to place a Henley's electroscope, which shows the increase of the charge of the electricity by the repulsion of the pith-ball. As the glass is electrified whilst passing the rubbers, and discharged when it comes opposite the metal combs, there are, then, only two quadrants of each circular plate that are simultaneously electrified. Attached to the rubbers are silk cases which inclose the glass plate nearly as far as the combs, these are to prevent loss of charge. To insure the proper working of the machine it is always necessary to have the room warm and dry; the glass legs supporting the conductors should be well cleaned before use, and wiped with a warm piece of flannel with a little paraffin oil upon it.

In 1772 Le Roy, a French physicist, constructed a glass plate machine with only one pair of rubbers; he had, however, two insulated cylindrical conductors placed horizontally at opposite ends of a diameter, one attached to the rubbers and the other to the metallic comb, thus he collected both kinds of charge. Winter, an Austrian, slightly modified Le Roy's machine to a form shown in Fig. 110, which is greatly used in Germany at the present time

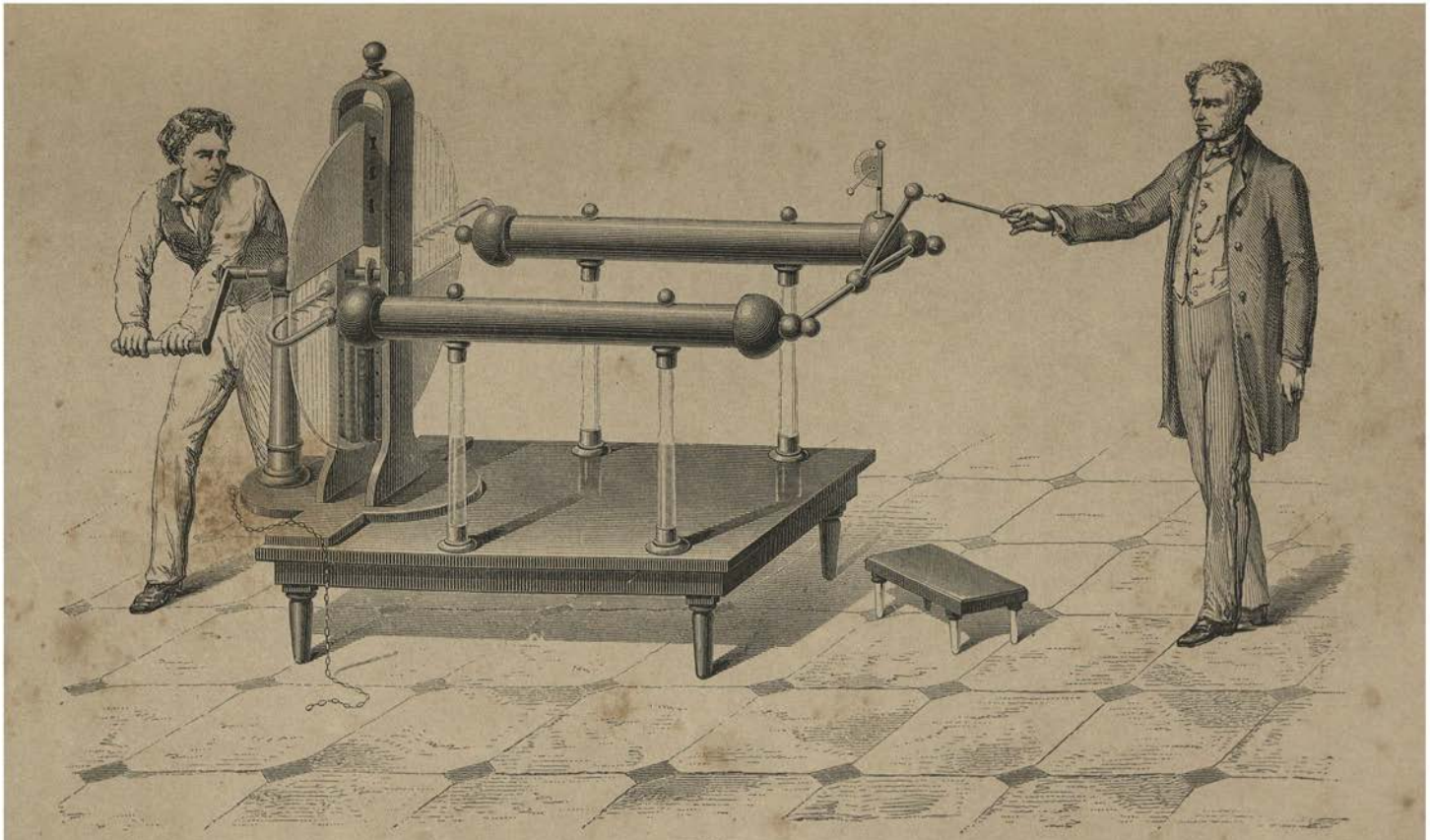

PLATE VI.—GLASS PLATE ELECTRIC MACHINE (RAMSDEN'S PATTERN).

The conductors are spheres; one is attached to the rubbers whilst the other is connected to the combs, which here take the form of two rings, one on each side of the glass. One conductor is charged positively, the other negatively. Winter's machine does not give a large quantity of electricity at each discharge, on account of the small size of the conductor, but it gives longer sparks than the other forms of machine of the same size. Nairne's machine (Fig. 111) is also arranged to give both kinds of charges. One of the conductors,

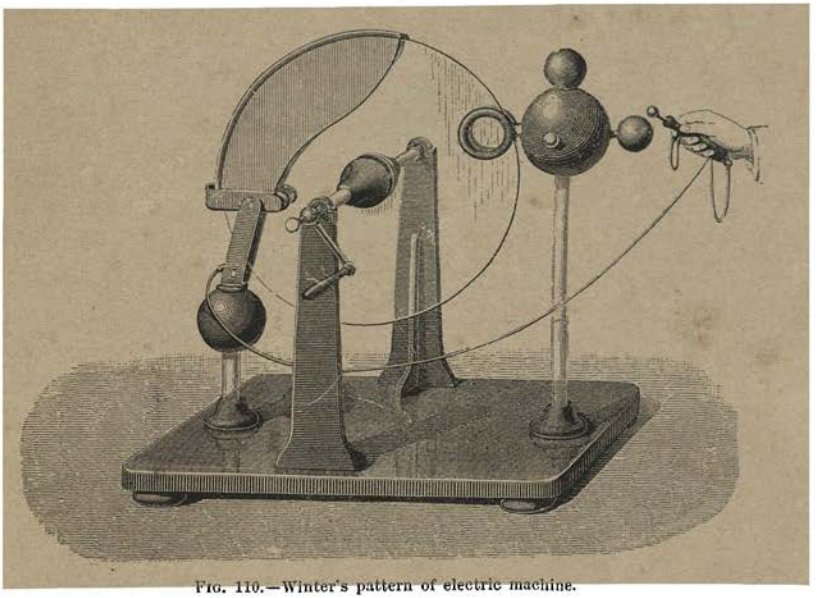

FIG. 110.—Winter's pattern of electric machine.

being furnished with a comb, is charged positively as in the plate machine, whilst the other conductor attached to the rubber is charged negatively. The form of the glass in this machine is a cylinder; it has a flap of silk attached to the rubber passing over it to prevent loss. It is, however, found best not to collect both kinds of charge, but to join one of the conductors to the earth by a chain or wire.

Van Marum[1] designed an electric machine (Fig. 112), like either

[1] The same physicist made a machine celebrated in the history of the science; it was shown amongst the Dutch historical collection of apparatus at the International Electrical Exhibition at Paris in 1881. It was made by Van Marum in 1787, and was modified by Cuthbertson during the following years. Two discs 1·62 metres in diameter turned parallel between eight pairs of rubbers; the metallic spheres terminating the conductors were thirty centimetres in diameter.

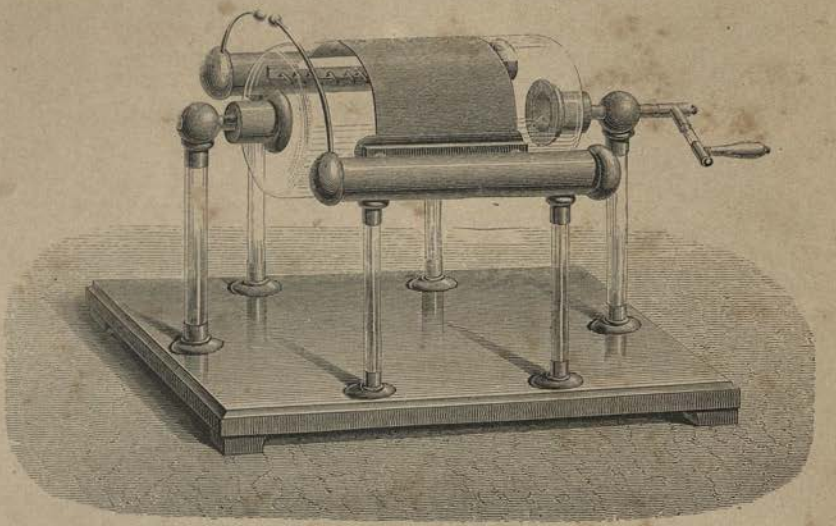

FIG. 111.—Nairne's pattern of electric machine.

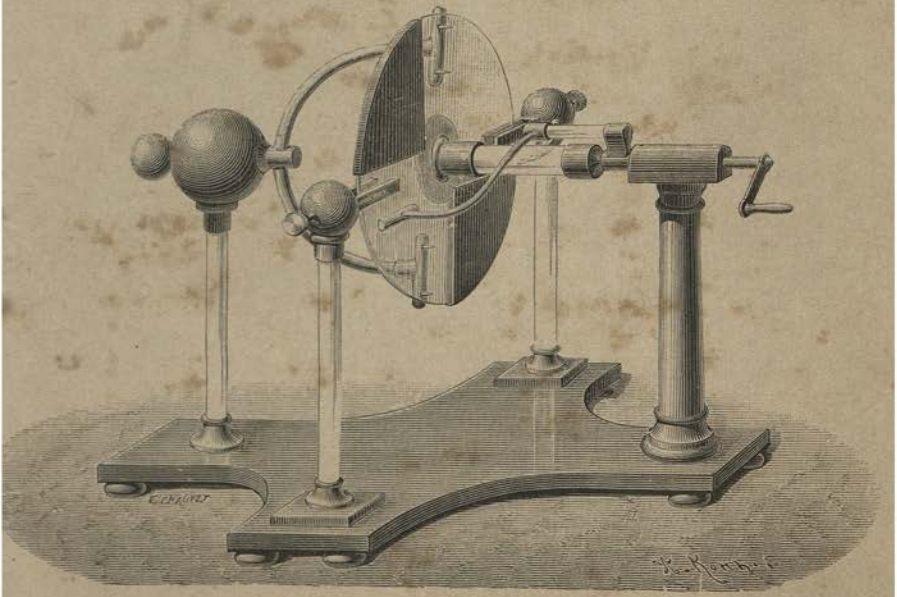

FIG. 112.—Van Marum's pattern of electric machine.

Ramsden's or Nairne's, capable of acting at will to collect either positive or negative charges, or both kinds at the same time.

If mercury be shaken up in a dry glass tube, a barometer tube for example, in the dark, a glow is seen, proving the production of

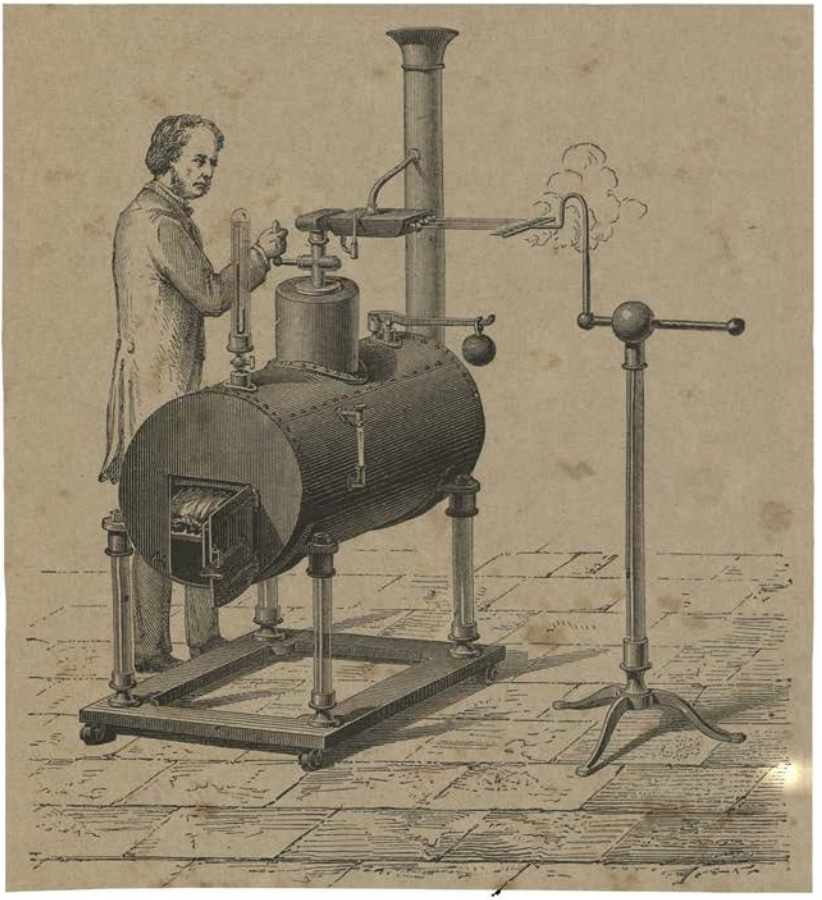

FIG. 113.—Armstrong's hydro-electric machine.

small charges of electricity. Sufficient, in fact, is produced to cause the tube to attract light bodies. Thus the friction of liquid bodies against solids can be used for the production of electrification. This

Van Marum made some curious experiments with this machine, especially on sparks and brushes, which he obtained up to 60 centimetres (24 inches) in length. We shall discuss this later on. This powerful machine is in the Teyler Museum at Amsterdam.

method was not used, however, until, in 1840, an accident[1] showed an easy method of producing large quantities by driving a jet of steam containing particles of water against a solid body. Such is the principle of Armstrong's machine shown in Fig. 113. An insulated boiler is filled with distilled water, and made to produce steam at a high pressure which escapes through a row of jets after being partly condensed by passing through pipes surrounded by cold water. The drops of water produced by the condensation strike against a plate of box-wood round which the steam has to pass before it escapes from the jets made of the same wood, as shown in Fig. 114, which is a section of one of these jets. Electricity is developed in proportion to the increase of the pressure of the steam; the jets become charged positively and the steam negatively. To collect the

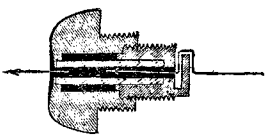

FIG. 114.—Orifice for issuing of steam.

latter charge an insulated conductor is used, which is furnished with a series of points held opposite the jets.

These hydro-electric machines are very powerful; but they are such a trouble to use that they were never adopted in place of frictional machines. There was one at the Polytechnic in London with forty-six jets, and which gave sparks two feet long; that at the Sorbonne, in Paris, has eighty jets, and gives sparks several inches in length.

[1] The discovery of the principles upon which this machine is constructed were made, it seems, by chance. "A mechanic was busy repairing a steam-engine near Newcastle, having one hand in a jet of steam which was escaping from a leak, with the other hand on the lever of the safety valve; he drew a brilliant spark and received a violent shock. Armstrong studied the conditions of the phenomenon," &c. (Mascart's *Traité d'Electricité statique*).

§ 3.—*Influence Machines.*

In the machines we shall now describe the charge on the conductor is obtained by influence.

These machines, which are rapidly replacing the old frictional machines, act on the principle of the electrophorus; that is to say there is a charge used to induce other charges in a neighbouring conductor; that neighbouring conductor being brought near, *touched while under influence*, and then carried away with its induced charge upon it. But since in these machines, as in the electrophorus, there is a gradual tendency to dissipation of the original charge, it is in these machines necessary to devise some means of continually replenishing the charge that is to influence the neighbouring conductors. Indeed, the replenishing action of these machines is something more: it operates continually to increase the fundamental charge up to a certain working limit. Hence a very small initial charge is requisite, this being speedily increased and multiplied by the action of the machine itself. There is, indeed, no need of friction to produce the working charge of electricity; it may be obtained from any source however feeble, the rest is done by influence after once the machine has been started. All good machines are self-exciting.

After the invention of the electrophorus by Wilke in 1762, and Volta in 1775, a "doubler," consisting of three metal plates, used as a sort of double electrophorus, was invented in 1787 by Bennet. But the first real influence machine was undoubtedly the "revolving doubler," devised by Nicholson in 1788. Nicholson also invented a "spinning condenser" on the same principle. In 1831 Belli described a similar apparatus, and in 1862 Varley patented a very perfect apparatus. But these inventions remained little known until 1865 when Professor W. Holtz produced the machine that has made his name famous. Simultaneously Professor Töpler, of Dresden, devised a very similar machine. In the following year Piche, Bertsch, and Carré in France, made machines on the same principle. The Holtz machine has received various improvements from subsequent workers. The latest and best machine is that of Wimshurst. We shall describe the more important forms in detail.

The ordinary form of a Holtz machine is shown in Fig. 115. It consists of two glass plates, A and B, on the same horizontal axis, and in two vertical planes very near together. The plate A, which is slightly larger than the other, is fixed, and has a large hole through its centre, through which passes the axle upon which the other plate, B, turns. Near the extremities of the horizontal diameter of the fixed plate two holes or "windows" are cut of trapezoidal shape; these are each furnished with paper "armatures" or "field

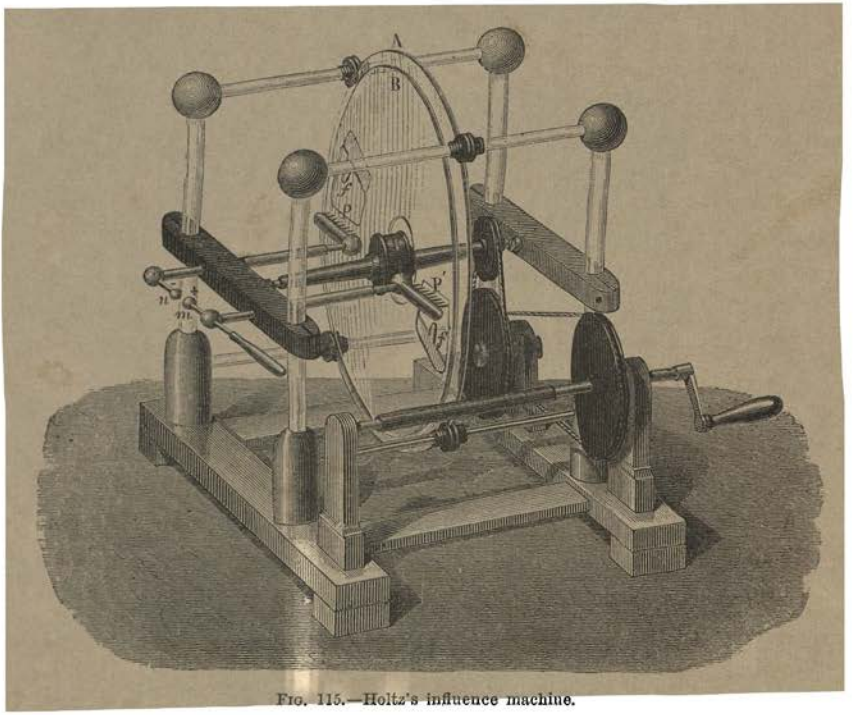

FIG. 115.—Holtz's influence machine.

plates" stuck on the outside face of the glass, and coming partly through the openings or windows in the shape of a finger, *f*, *f*'. Two insulated conductors terminated by combs are brought close to the movable plate and directly opposite the windows of the fixed plate; these conductors are bent at right angles and are terminated by knobs, *m*, *n*, which can be brought together at will. In the figure each part of the machine is shown supported on insulating pillars of glass, including the fixed plate, which is held by horizontal supports

across the vertical pillars. The movable plate is rotated by a train of pulleys at a speed of five or six turns per second.

To start the machine, the two knobs of the conductors are pushed together. The movable disc is turned by the handle in the opposite direction to that in which the tongues of the paper armatures point. One of these paper armatures is then electrified, by bringing near it a piece of ebonite rubbed with cat's skin. Soon there is heard a crackling of the electricity escaping from the points of the comb. When the machine is once charged in this way, it continues to supply itself as long as it is rotated. If now the terminals of the conductors be separated a continuous stream of sparks is obtained between them.

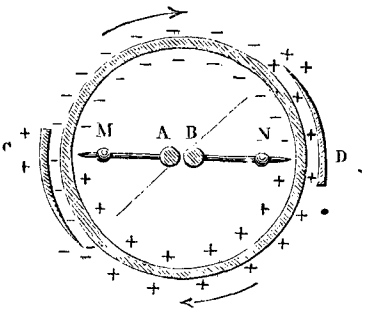

FIG. 116.—Diagram of action of Holtz machine.

Let us now explain what passes, and let us give a short theory of the machine, as we have just described it. In Fig. 116 C and D represent the paper armatures on the fixed plate, A and B the conductors terminated by the points M and N corresponding to the metal combs of the machine. The movable plate has been replaced in the diagram by a circular line, for the sake of ease in demonstration. The arrows show the direction of rotation against the tongues of the paper armatures.

A rubbed piece of ebonite is brought near the broad part of the paper armature C, thus inducing a positive charge in the near part of the paper, leaving the tongue negatively charged as indicated in the figure by the signs. This tongue can set up an electric wind, producing a discharge against the back of the rotating glass. At the same time the conductor A B which as the knobs are

touching is continuous, is acted upon inductively by the paper armature. The armature is positive, therefore a negative charge escapes as a wind from the comb M on to the glass, and a positive wind issues from the comb N. The other paper armature thus becomes electrified by induction, and we get positive wind discharged at its point, leaving its wide part negatively charged. The result is that the rotating glass plate becomes charged on its two faces, front and back, one half with negative electrification and the other with positive. The mutual reactions of these contrary charges both

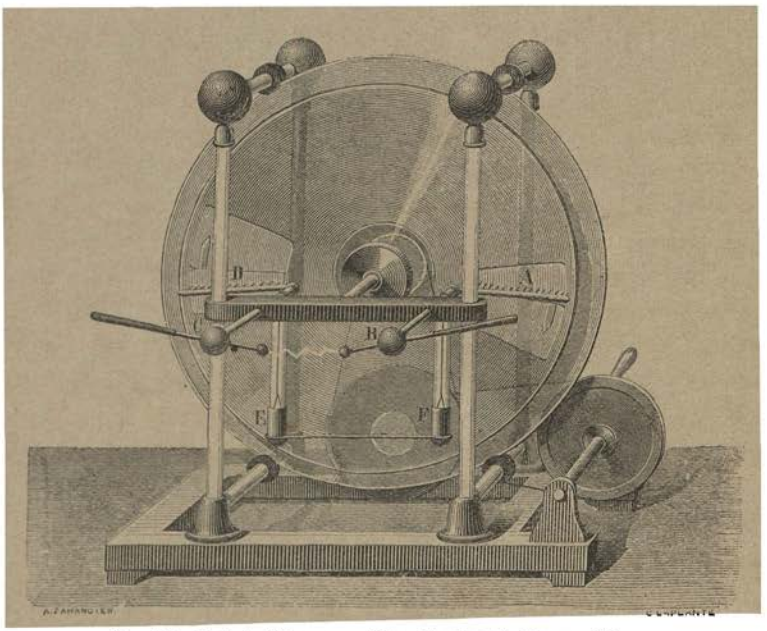

FIG. 117.—Holtz's influence machine, showing the two small jars.

from the paper points and the combs increase the flow of electricity; and accumulation goes on in a geometric progression, or would go on were it not for loss by leakage through the supports and by discharge into the air. Fig. 117 shows the machine with two condensers in the form of small Leyden jars attached to the conductors so as to increase their electric capacity, the inner coating of the jars being attached to the two conductors, B, C, whilst the outer coatings are joined together. By this means the size of the sparks can be regulated. When the knobs of the conductors are brought close

together a great number of small sparks are observed, but if the knobs be far separated we can obtain longer sparks, but at greater intervals of time.

The Holtz machine is very powerful, but it is very sensitive to the moisture of the atmosphere and to dust. When made of equal size, and driven at the same speed, it will yield twenty or thirty times the amount of electricity that a Ramsden machine will yield. Although when dry and cold it works extremely well, yet if at all moist, as on a hot autumn day, or before a large audience of people, it requires a great deal of skill and various precautions to get anything out of it. These evil effects can be got rid of by drying the air of the room where the machine is, or better, by placing the machine on a table pierced with holes, and under which is a brazier of hot charcoal, the hot air from which can rise up and thoroughly dry the machine.

Holtz machines are also built double, that is to say with four plates, two stationary and two movable ones fixed on the same axle. The combs of these machines are curved round like a horse-shoe, so as to come opposite both paper armatures. These double machines give more electricity and thicker sparks than single machines; but above all they retain their charge for a much longer time in a dry atmosphere, they remain electrified for several hours and will start as soon as the plates are turned without fresh charging.

A second pattern of Holtz machine is shown in Fig. 118. The plates are glass, and are of the same diameter, they are arranged horizontally and both move, but are driven in opposite directions. Fixed plates and paper armatures are done away with in this machine, but there are four comb-conductors, connected in pairs by metal ties. There are two combs at the extremities of one diameter above the upper plate, and two at the extremities of the diameter at right angles to this are below the lower plate. These conductors are insulated on supports of ebonite or glass, but as we have just said are united above in pairs, so that they can be connected or disconnected at will. Just as in the ordinary Holtz machines, to start the machine the conductors have to be put into contact, and a piece of electrified ebonite is brought near to one of the combe, when on turning the machine a crackling is produced, showing that

the machine has started. The ebonite is then removed and the conductor knobs separated, when we have a continuous stream of

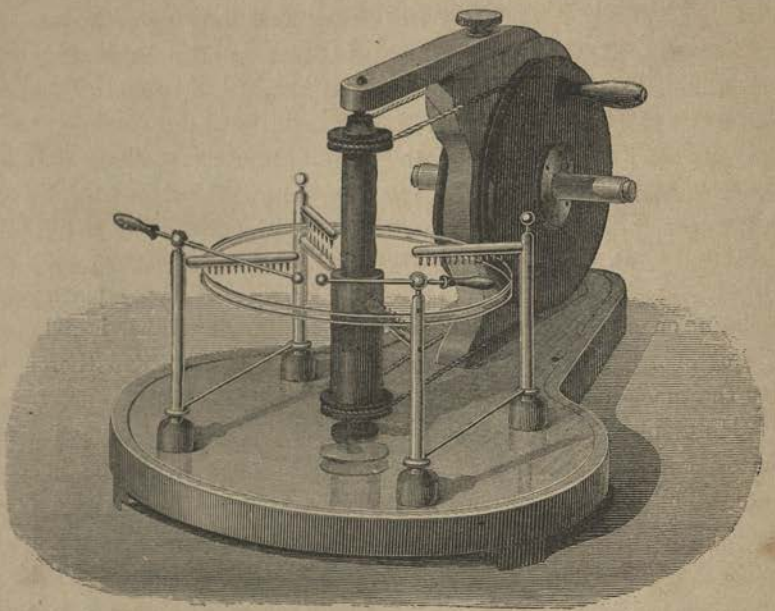

FIG. 118.—Holtz's second type of influence machine.

sparks. The theory of this machine is almost identical with the ordinary Holtz machine.

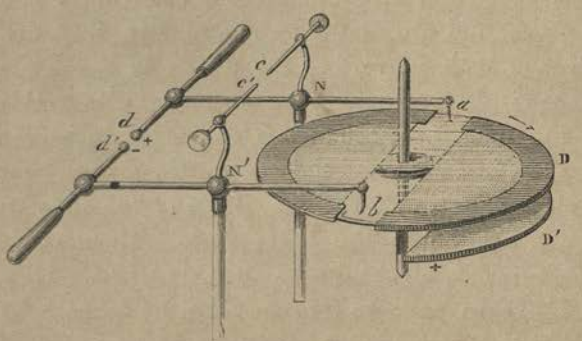

FIG. 119.—Töpler's influence machine.

The Töpler machine is shown in its simplest form in Fig. 119. A disc of glass, E, turns about a vertical axle, H, by means of a

system of cords and pulleys. On its lower face are fastened two segments of tinfoil, which turn over on to its upper face in the form of two bands, C D, separated by a diametral gap. Two conductors, N N′, carried on insulating feet, are brought over the extremities of this space, and their terminal knobs are furnished with two flexible springs of metal wire, *a*, *b*, bent in opposite directions. Under the movable disc is an insulated conductor, D′, of the same shape as one of the segments; this remains stationary and acts as an inductor. Let us now suppose that the inductor D′, is charged positively. The segment D is electrified by induction as is also the conductor N*a*, these being electrically one and the same while *a* is in contact with the tin-foil band D, as is the case a moment earlier than is shown in the figure. D is thus left negatively charged whilst the other end of the conductor N is charged positively. As soon as the segment D leaves *a* it is put into contact with *b*, to which it communicates its negative charge: or in other words *b* and N′ have to give up some of their electricity to the negatively charged D′, and so they also are left negatively charged.

The same succession of events occur with C, and thus as the plate goes round this action is repeated again and again, and each conductor goes on accumulating a larger quantity of its respective charge, in geometrical progression until when a discharge takes place between the knobs of the conductors, which can be placed at any desired distance apart.

Fig. 120 is a drawing of a Töpler machine as shown at the International Exhibition at Paris. Fig. 121 is another form of Töpler machine in which twenty plates are used instead of two as in the original form. The idea is to increase the production and the output of electricity by rotating many plates at the same time.

Fig. 120 shows the several parts arranged more like those of a Holtz machine. The fixed plate consists of a polygonal sheet of glass divided obliquely in two parts with a space between running diametrically. The back of this plate has two sheets of tinfoil which act as *inductors* or "*field-plates*," and correspond to the paper armatures of the Holtz machine. In front is the movable glass disc which has near its periphery *sectors* or "*carriers*" of tinfoil, each furnished with a small metallic boss. The combs of the conductors have their points fitted with a small soft wire brush, that touches

the bosses on the tin sectors each time that the latter pass under the former. These sectors are subjected to the influence of the inductors stuck on to the hinder face of the fixed glass plate. There are three sets of conductors armed with brushes. The horizontal pair act merely as a discharging apparatus for taking the sparks. The

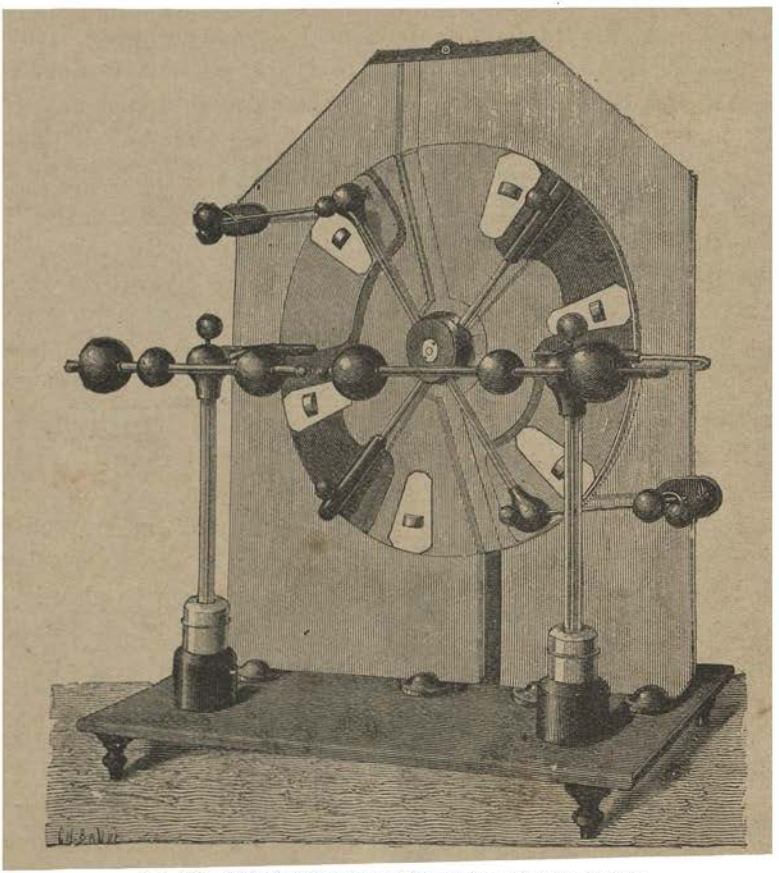

FIG. 120.—Töpler's influence machine, as shown in 1881 at Paris.

next pair sloping downwards from right to left in the cut are simply connected together. The third pair are used each one to keep its own inductor supplied with a charge. The "sectors" as they pass (rotating left-handedly as viewed in Fig. 120) in front of the inductors are acted upon inductively. Just as they pass onward, but while still under influence, they are touched by the

second pair of brushes, which need not be insulated. They go onward charged and give up their charges to the third pair of brushes which replenish the inductors. When the inductors are charged up to their limit the third pair of brushes no longer take the charges from the sectors, which then give up their charges to the discharging apparatus. One of the inductors is of course charged positively, the other negatively, as in the Holtz machine. It is sufficient to charge one of them slightly at first; but the best machines do not even require this, the slight friction of the brushes on the sectors

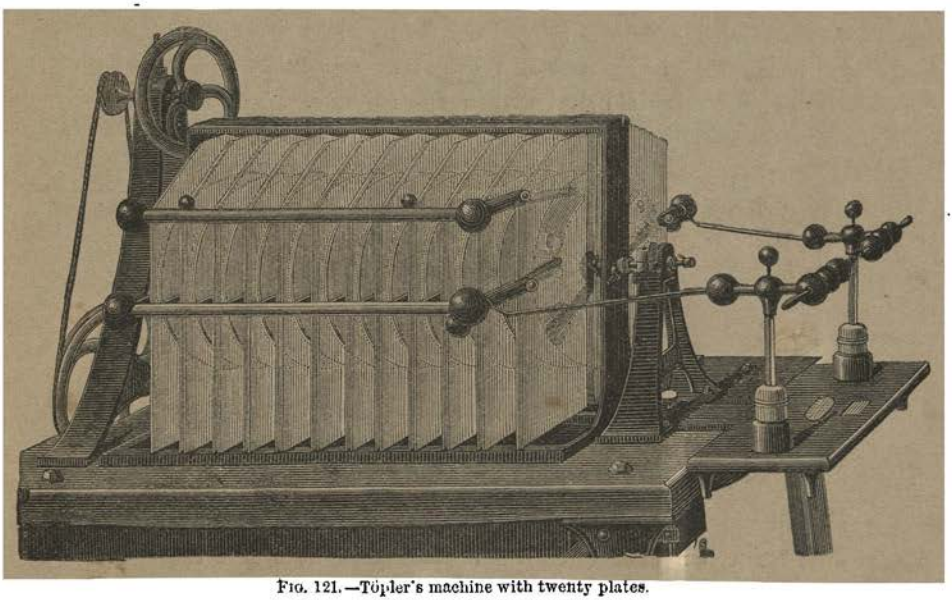

FIG. 121.—Töpler's machine with twenty plates.

being sufficient to produce the minute initial charge. The Töpler machine as manufactured by Voss is sometimes in England known as Voss's machine.

Varley's machine was almost identical with the preceding, but had only two pairs of conductors.

We now come to the machines of Bertsch and Carré. In the first of these a disc of ebonite turns about a horizontal axis and is given a rapid rotation by means of a system of pulleys and cords. To start the machine a sector of ebonite (Fig. 122), previously electrified, is held near the lower part of the disc, and remains there

while the machine is worked. On the other face of the disc are two conductors armed with combs, one of which is opposite the excited piece of ebonite. This comb is acted upon inductively and a wind is set up at its points which electrifies the rotating disc, the charges being carried round to the opposite comb and discharged there.

The machine as thus described was first designed by M. Piche, and afterwards improved by M. Bertsch, but it is inferior to the Carré machine and to the Holtz and Töpler machines, as it has no arrangement for replenishing the inducing charge. It is literally nothing more than a rotating electrophorus.

The Carré machine (Fig. 123) only differs from the above by having instead of the sector, a disc P P of ebonite, which is itself movable and turns slowly between two rubbers. The result is that

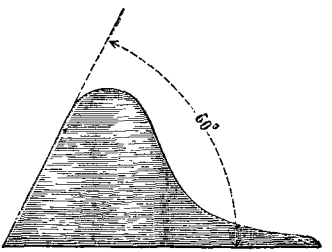

FIG. 122.—Sector of ebonite of Bertsch machine.

the inducing body instead of losing its charge, as with the sector in the Bertsch machine, keeps it up the whole time that the machine is in use. The same pulley that drives the main disc keeps this disc in rotation but is driven at a much slower rate. With a lower disc of 38 centimetres in diameter, and an inductive disc of 49 centimetres, sparks were obtained from a Carré machine 20 centimetres long.

The inconvenience attached to this apparatus is, that the ebonite is subject to be affected by the atmosphere. This can be removed by polishing the disc from time to time with emery paper, which, however, removes a thin layer. The machine may be looked upon as a combination of friction machine and electrophorus.

The latest of influence machines, and the best, is that of Mr. J. Wimshurst; it resembles Töpler's machine in having metal carriers

but has like Holtz's second form two oppositely revolving discs of varnished glass. Fig. 124 gives a view of one of Wimshurst's machines. His largest has discs seven feet in diameter; the smallest yet made has discs that are in diameter but one inch. Upon each disc is fastened a number of segments of tinfoil or thin sheet brass, the spaces between being varnished with shellac varnish. In front of the front disc, at about 45°, is fixed an uninsulated

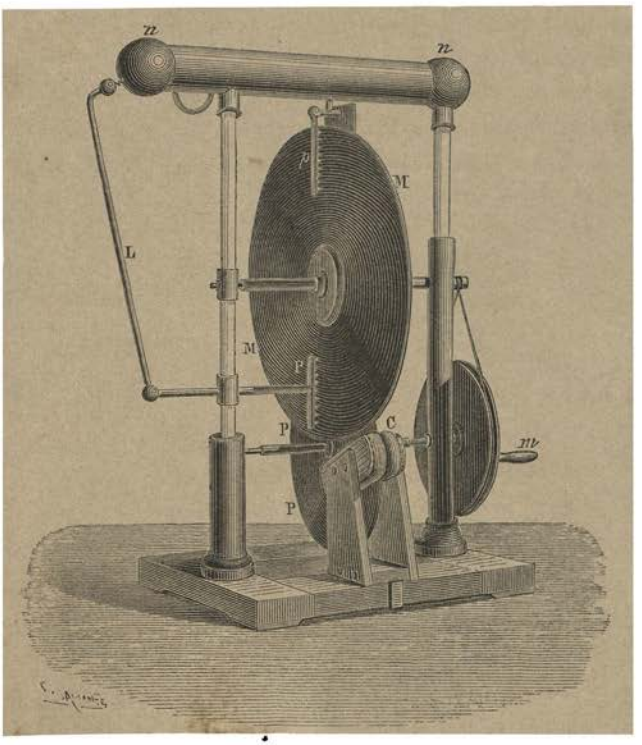

FIG. 123.—The Carré machine.

diagonal conductor, armed at each end with a small brush of flexible wires which touch the metal sectors as they rotate. At the back a similar diagonal conductor is fixed at right angles to that in front. Right and left a pair of combs are carried on insulating supports, these combs almost touching the discs. They are in communication with the discharging apparatus. In this machine the metal sectors act both as inductors and as carriers. Suppose the

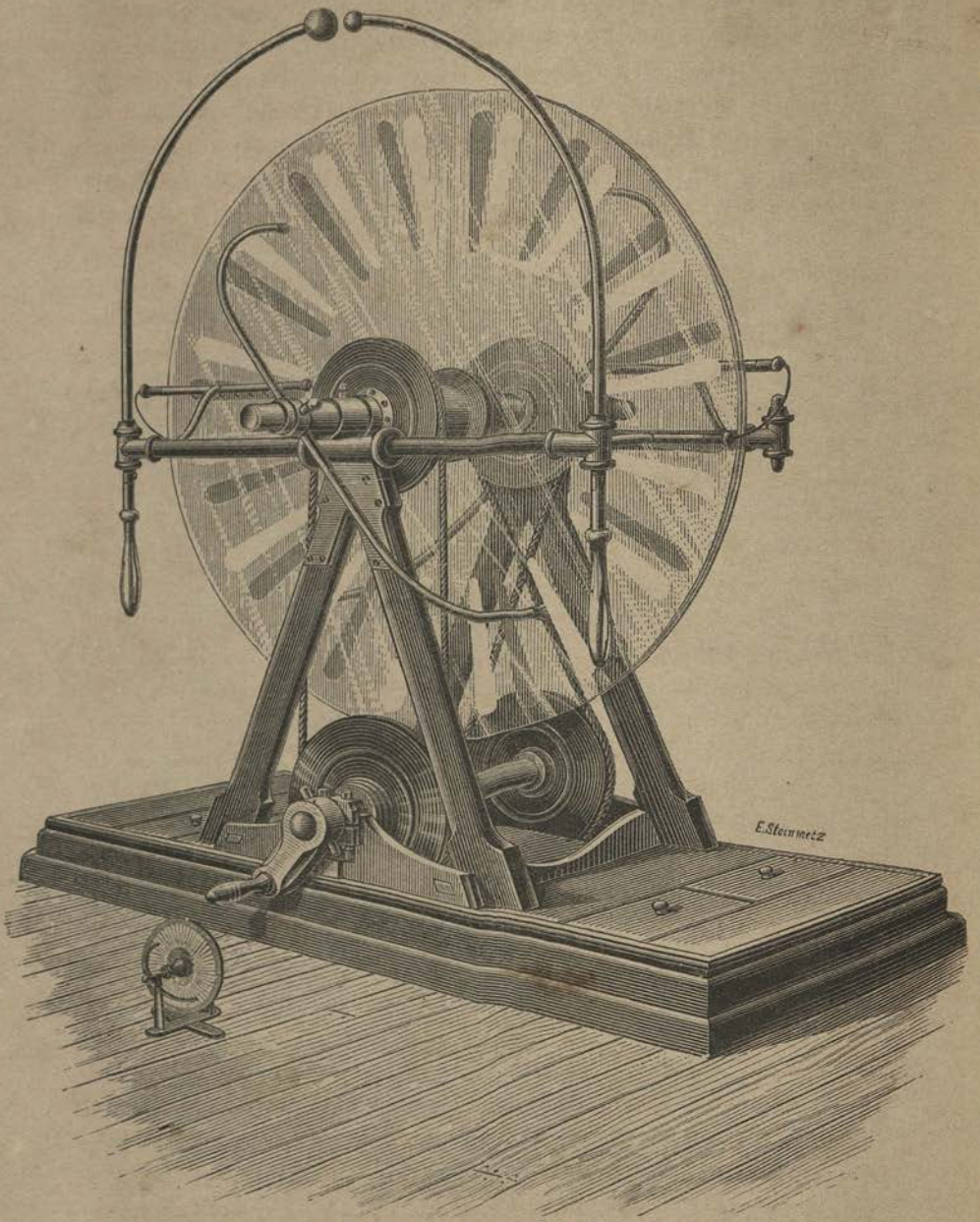

FIG. 124.—The Wimshurst influence machine. (From *Engineering*.)

front plate to be rotating clock-wise, and the back plate counter clock-wise. If the metal sectors descending from the summit on the left on the back disc are charged positively, the metal sectors on the front disc ascending on the left will be under influence, and, if touched under influence by the diagonal conductor as they pass under it, will acquire a negative charge. As these negatively-charged sectors of the front plate advance towards the right they will come to a point where they are opposite to the upper end of the hinder diagonal conductor, and here, whilst still acting as carriers to bring the negative charge round to the right side, they will act as inductors and will influence the sectors of the back disc, which, as they are in turn touched by the hinder brush, will acquire positive charges. The sectors on the front disc will therefore constantly carry a negative charge as they move over the top from left to right, and those of the back disc will carry a positive charge from right to left. In the lower halves of their respective rotations the inverse of these actions will hold good, the front carriers conveying positive charges from left to right. The result will of course be that the two main conductors on the left and right will become respectively positively and negatively electrified. In these machines no initial charge is necessary. If dry and free from dust the machine is certain to excite itself after a couple of turns.[1]

A small form of influence machine, having a cylinder of ebonite with strips of tinfoil upon it, rotating within an outer cylinder which has two inductors or field plates of tinfoil upon it, is now largely used as a portable *gas-lighter*. Another small influence machine known as the *mouse-mill* is used in Sir W. Thomson's siphon recorder (see Chapter on Telegraphy), to electrify the ink siphon.

§ 4.—*Various Experiments with Electrifying Machines.*

A great many very curious experiments can be made with electric machines, such as we have just described. In describing some of the most interesting of these experiments, our idea is to familiarise our-

[1] The usual size of discs in Wimshurst's smaller machines is from 14 to 17 inches. The large machine just described was constructed by Mr. Wimshurst for the Science and Art Department's Museum at South Kensington.

selves with the explanations of the phenomena described in the foregoing chapters, rather than to attempt a complete study of any of the varied phenomena.

A metal rod is suspended in a horizontal position from one of the conductors of an electric machine by a metal hook. Three bells are hung from the rod, the two end ones by brass chains, and the middle one by a silk string; but this last one is put into communication with the earth by a brass chain. Between the bells are hung (by silk strings) two small brass balls (Fig. 125). When the machine is worked the electricity spreads to the two end bells, the two balls are then each attracted, and after contact are repelled. The central bell which was in a neutral state becomes charged by influence with a

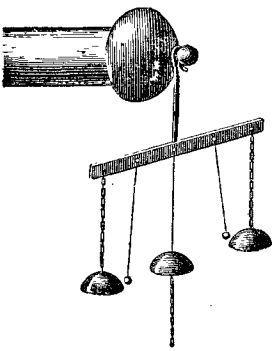

FIG. 125.—Electric chimes.

charge of the opposite kind, this then attracts the two balls which as soon as they touch the centre bell are discharged and fall back. This series of effects is repeated indefinitely, the bells being sounded by each contact of the balls, as long as the machine is worked. This apparatus, devised by Franklin, has received the name of the *electric chimes.*

Fig. 126 shows an experiment designed by Volta to explain the phenomena of the jumping of hailstones in storms. It consists of a glass bell jar resting on a metal plate in connexion with the earth; through the neck of the jar passes a rod, the lower end of which is attached to the centre of a metal disc, whilst the upper end is in connexion with the knob of an electrifying machine. Inside the jar are a number of pith-balls. As soon as the machine is started the

electricity spreads to the metal disc and acts by influence on the pith-balls which rise up and strike against it; they then immediately fall back electrified and discharge themselves against the metal bottom and are again attracted. These motions are continuous whilst the machine is being worked. This experiment is known as the *electric hail.* Sometimes the pith-balls are replaced by small figures cut out of pith, which dance between the plates.

The *electric water-pot* furnishes a good illustration of the repulsion of electrified particles. It consists of a metallic vessel, filled with

FIG. 126.—Electric hail.

water, furnished on the top with a metal hook, and near the bottom are several capillary jets through which the water only slowly drops when unelectrified; but as soon as it is electrified the water issues from the jets in a continuous stream,[1] or the jets divide into fine drops which in the dark appear luminous. The yield of water is not increased however, the phenomenon being due to the breaking up of

[1] It is in this manner that a jet of ink is made to spirt from a fine glass siphon in the instrument called the *siphon recorder*, invented by Sir William Thomson for registering signals through Atlantic cables.

the drops into smaller particles owing to the mutual repulsion of the particles when under the electrical action of the machine.

We have seen that if an insulating body, a stick of glass for instance, has been electrified, on bringing your knuckle near it a small spark may be obtained accompanied by a slight crackling noise; the glass however remains electrified everywhere except where the spark was drawn. This is due to the non-conductivity of the glass. If a conductor be substituted for the non-conductor, such as the charged conductor of a machine, the effect produced is much more energetic and the discharge is much more complete.

If one's knuckle be brought to any other part of the conductor a spark can be drawn the intensity of which depends upon the amount of the charge on the machine. The repulsion electroscope, fixed to the conductor as in Fig. 102, then falls to zero, showing that the

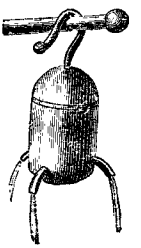

FIG. 127.—Electric water-pot.

machine is completely discharged. But if the plate of the machine be continually turned a rapid series of sparks is obtained which causes a snapping sound, and a continuous prickling sensation is felt. If the hand is at a considerable distance from the machine the charge must accumulate until the electric stress upon the intervening air becomes so great that a spark pierces its way across the space; and in this case a much longer spark is obtained, giving a shock which may be felt all along the arm. If, whilst the machine is being worked, some person stand on an insulating stool and put himself in connexion with the machine by laying his hand upon it he then becomes electrified and in fact forms part of the conductor. Any one not insulated can now draw near and take sparks from any part of the insulated person.

The luminous effects produced by the electric discharge will

be treated separately and in a more detailed way. We will return to them after we have described the various ways of producing electrification. We will now describe some experiments on the spark.

On the inside of a tube a series of small lozenges of tinfoil is fastened in the form of a helix, there being a small space between each. The two extremities of the tube and helix are attached to metal caps. One end of the tube is then put in proximity to the conductor of a machine, the other end in connexion with the earth (Fig. 128). As soon as the machine is charged each metal bit constitutes one of a chain of particles which are all polarised or put under influence, and presently sparks jump at the same instant across all the gaps, giving a pretty spangled appearance.

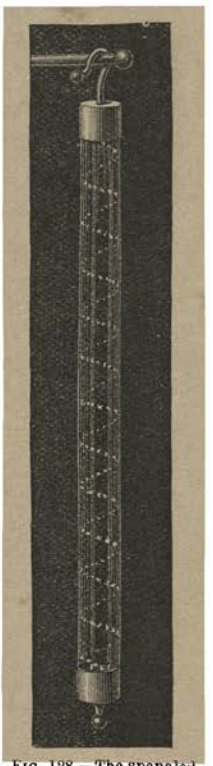

FIG. 128.—The spangled tube

Similar effects are produced by arranging little discs of tinfoil on the surface of a globe in patterns (Fig. 129): a luminous line of sparks is observed to light up the globe.

If on a sheet of glass strips of tinfoil are stuck, forming an uninterrupted series of parallel lines, as is shown in Fig. 130, any pattern can be cut in it by means of a sharp point; a spark can then be passed from a machine across each rupture in the foil from end to end of the series. The pattern traced on the plate will then be shown by a series of bright sparks. A pretty variation of this experiment consists in varnishing a plate and then sprinkling over it filings of zinc, copper, or iron. Then, when one edge of the plane is put in connexion with the machine and the opposite edge with the earth, sparks are seen to pass in very irregular lines between the various particles; their direction and colour continually changing.

In the experiments that we have just described the discharge takes place between two oppositely-charged points or surfaces separated one from the other by an insulated medium such as air

or glass: such discharges are called *disruptive discharges*, to distinguish them both from the *conductive discharge* through metal wires, and the *silent discharge* of the electric wind at points.

The following experiments prove that the *disruptive discharge* is accompanied by a violent motion among the particles of the insulating medium.

Two tubes of unequal diameter are in connexion at their lower extremity; the larger one is closed above whilst the smaller one is

FIG. 129.—The spangled globe.

open; they contain some water (Fig. 131). In the large tube are two metallic rods terminated by balls, one coming through the top, the other through the bottom of the cylinder; the first one being in connection with the machine, the second one with the ground. When a spark is passed between the balls the water is observed to be forced into the open tube. If the spark be very strong it may even throw the water out of the tube. This agitation is produced by the violent motion of the particles of air and by the expansion of the air due to the rise in temperature, but not to this alone, as was believed by

Elijah Kinnersley, who devised this experiment. The proof that the air is heated is that it does not immediately fall to the same level in

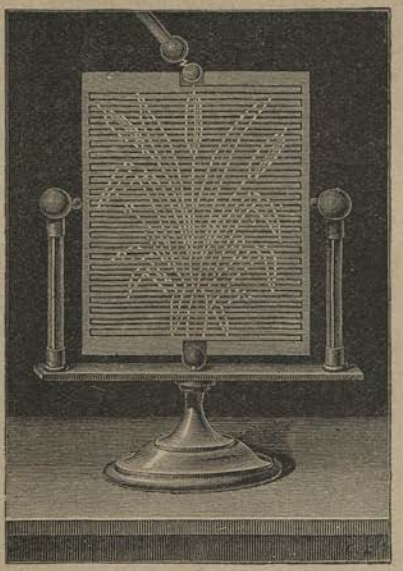

FIG. 130.—The luminous picture.

both tubes. This apparatus, with or without a fine wire connecting the two balls, is called Kinnersley's thermometer.

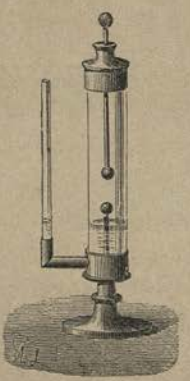

FIG. 131.—Kinnersley's electric thermometer.

The electric mortar (Fig. 132) has been designed to show the violent expansion of the air. At the moment that the spark takes

place the ball is thrown into the air; this effect is still more increased if a few drops of ether are put in the mortar just before the experiment, as the vapour of ether, when mixed with air, is explosive.

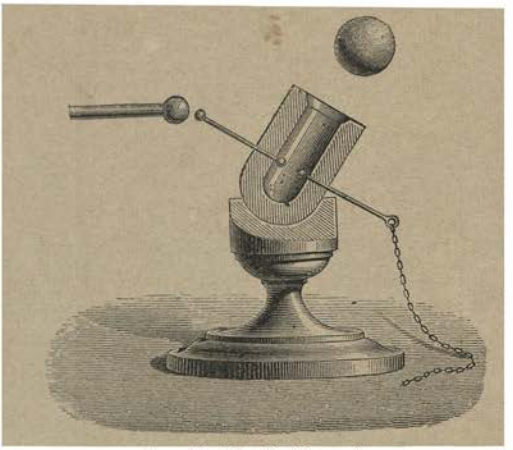

FIG. 132.—The electric mortar.

The spark can also be made to pass through water. For this purpose two conducting rods, which lead, one to the machine *m*, the other to the earth *t*, are covered with gutta-percha, which insulates them from the water except at the ends which are bare and which are brought near together. It is between these two points that the

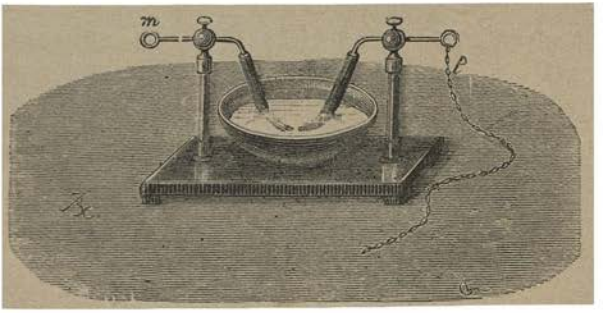

FIG. 133.—Electric discharge in a liquid.

spark passes and the water is thrown about. If the glass vessel is a closed one it is usually broken by the sudden discharge. The experiments that we have just described are very easily repeated by any one who has any such apparatus.

CHAPTER V.

THE LEYDEN JAR.—CONDENSERS.

§ 1.—*Cuneus's and Muschenbroek's Experiments; The Discovery of the Leyden Jar.*

CUNEUS, a pupil of Muschenbroek, a celebrated physicist of the last century, was one day trying to electrify some water in a wide-necked bottle. For this purpose he held the bottle in one hand after having placed in the bottle a metal rod connected to the machine. When he thought the water was sufficiently electrified, he tried to remove the iron rod with one hand, without loosing his hold of the bottle with the other hand. He received a shock that surprised him. Muschenbroek repeated Cuneus's experiment, but the shock that he received in his arms, shoulders, and chest was so great that he lost consciousness, and was so frightened that, in writing to Réaumur about this, then new, discovery, he wrote that for nothing in the world, not even for the crown of France, would he go through it again. But some other physicists were less fearful. Allaman, Lemonnier, Winckler, and the Abbé Nollet varied the experiment in all sorts of ways, and so a new piece of apparatus was added to electrical science: this apparatus, called the *Leyden jar*, is named after the place where the experiment was first performed in 1746.[1] At the present time the apparatus is made in the following way:

A thin glass bottle is taken; the outer surface up to three-quarters

[1] A very similar experiment was made, it is said, in the previous year by Von Kleist, Bishop of Pomerania. Having pushed an iron rod through the cork of a bottle full of mercury, he held the rod to the conductor of an electric machine. He accidentally touched the conductor with his other hand whilst the rod was touching the conductor, and received a violent shock in his arms.

of its height is covered with tinfoil or other thin sheet of metal: this sheet constitutes the *external coating*. The *internal coating* is made of tinfoil, and covers the bottom and the sides, but usually does not extend quite so far up as the external coating. Sometimes the flask is filled with leaden shot, or with pieces of gold-leaf or tinsel; Muschenbroek filled his bottle with water, but in every case a conductor is used. The neck of the bottle is closed with a wooden stopper. Through the centre of the stopper passes a brass rod, terminated on the outside by a knob or hook, and on the inside communicates with

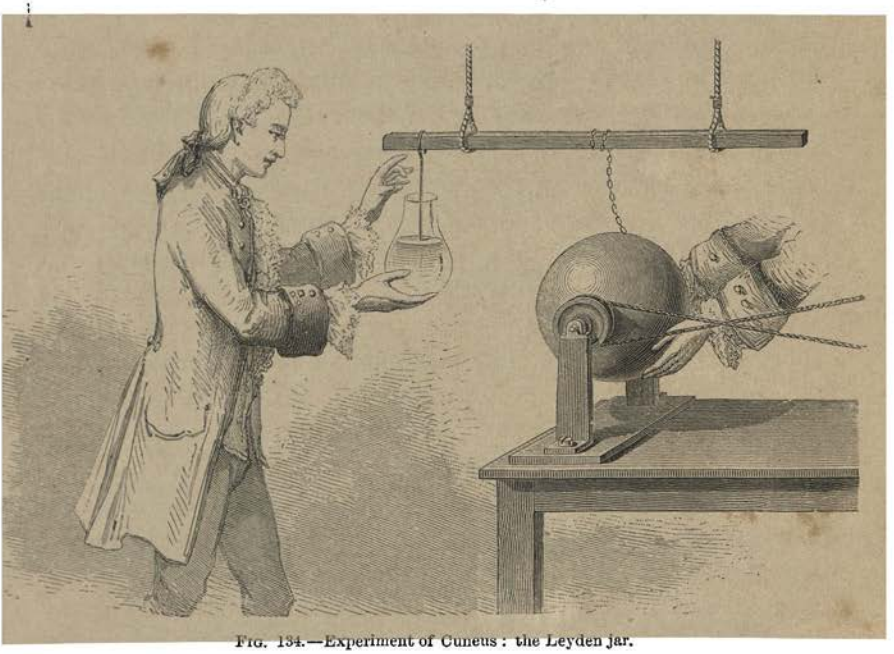

FIG. 134.—Experiment of Cuneus: the Leyden jar.

the metal coating. To preserve the insulation of the glass, it is found best to varnish the outside. Without this precaution, the glass would soon be covered with a very thin film of moisture, which does not completely insulate the two coatings, and it then happens that discharges take place or sparks occur along the surface of the glass. To charge the Leyden jar, the inner coating is put into contact with the conductor of an electric machine, by means of the brass rod, whilst the outer coating is put into connection with the earth, either by means of a chain or by simply holding it in the hand. It is possible,

but not usual, to charge the jar the other way, putting the inside coating into communication with the earth, and the outer coating with the machine. When the jar is charged, if a conductor be made to join the outer coating with the knob, a sudden discharge takes place with a loud noise and a short brilliant spark.

For example, hold the jar in one hand, and place the other hand on the knob, the discharge will pass through the arms and body, and one will experience the shock that was so strange and so frightened the first persons who tried it. If several people form a chain by taking hold of hands, the first of the series taking the jar and holding it towards the last, as soon as contact is made the same effect will be felt by each at the same time. Nollet made this experiment before Louis XV.: three hundred of the French guards formed the chain, and simultaneously received the shock produced by the discharge of a Leyden jar.

Before passing on to describe several curious experiments with this apparatus, we will explain the theory of the double phenomenon of the charge and discharge of the jar.

We shall at once observe that the apparatus consists of two conducting bodies, the exterior and interior metal coatings, and of the insulating body which separates them, namely, the glass jar. When the knob or hook is put into contact with the conductor of a machine, the electrification, say positive, spreads all over the inner coating and charges it. This charge then acts by influence on the outer coating, repelling electricity out of it through the support on which it stands, leaving the outer coating negatively charged at that part of it, namely the surface next the glass that is nearest to the inner coating. Then this negative charge acts in turn inductively on the positive charge of the inner coating, and it is impelled the more strongly towards the outer coating. So it comes about that the mutual influence of the two opposite kinds of charge urges them towards one another, and they are only prevented from uniting by the intervening glass jar. They can, however, be allowed to neutralise one another by simply connecting the outside coating with a wire to the knob, when a spark, accompanied by a sharp snap, takes place. The glass, indeed, plays a double part here. It is concerned in the phenomenon of influence, having, as we mentioned in the preceding chapter, a special inductive power or dielectric capacity of its

own. It also serves the mechanical function of preventing a spark discharge from occurring between the inner and outer coatings of tinfoil.

At a glance, the size of the spark and the noise show that we are here dealing with an actual quantity of electric energy considerably greater than that concerned in the small sparks obtained direct from the electric machines. The accumulation of electrification is out of proportion with the mere size of the conductors of

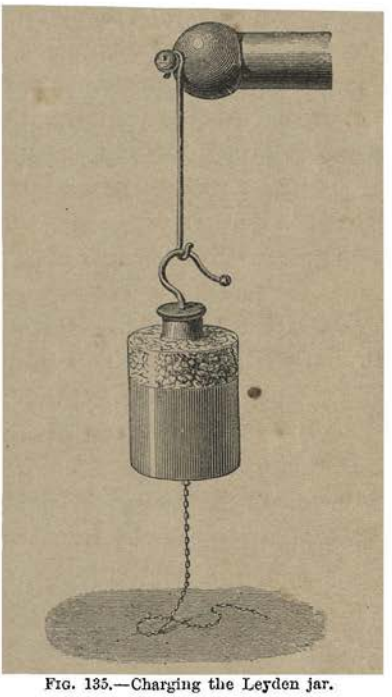

FIG. 135.—Charging the Leyden jar.

the apparatus. Here is also another point to be explained. After a Leyden jar has been discharged, if it be allowed to stand for some time, it will be found to contain a charge, without having again been put in connection with a machine, and one can get a second spark from it, much weaker, however, than the first; sometimes even a third spark can be obtained. To this phenomenon the name of *residual charge* is given. A Leyden jar need not be made actually in the form of a bottle: it is found that any form of

glass will answer, provided only the two metal surfaces are kept apart by a suitable layer of glass or other dielectric. Such arrangements are called *condensers*, from their property of taking in a large charge, and as it were condensing it into a small space.

§ 2.—*Theory of Electric Condensation.*

The condenser as designed by Æpinus is shown in Fig. 136. There are two insulated metallic plates, A, B, arranged opposite to one another, on two glass supports, and separated by a disc of glass. They both slide in a groove, so that the distance between them can be varied, and they can be brought so as to touch one on each side of the insulating disc. In the figure there are also shown some little repulsion-electroscopes of Henley's pattern placed one on each of the metal bearings that support the condenser plates.

Let us suppose that the plates are far apart, and let A be put into connection with the machine. This plate will be electrified positively, to a degree equal to that of the machine: the pith-ball of the electroscope on that side rises. Further be it noted that the electrification is very nearly equally spread over both faces of the plate. After having separated the plate A from the machine, let it be brought, as in Fig. 137, nearer to the other plate, B. Under the influence of A the plate B will become charged, negatively on the face towards the glass plate, and on the other face positively; its pith-ball will also rise. Now that the front surface of B is left in a negative state there will be a tendency for the electricity of A to move as far as it can towards B, and accordingly it will accumulate on the surface nearer towards the plate B; and the pith-ball on A will fall down because the charge has left that part of A.

If B be now put into connexion with the earth, the repelled charge (positive) escapes, and a further action takes place. The negative charge concentrates on the front side of the plate B more than previously, and by reaction the density of the positive charge on the plate A increases on the face nearest B, whilst the exterior face is left practically unelectrified. Then, if the connexion be now re-established between the machine and A, a fresh supply of

electricity will pass over from the machine to *A*, which will further charge it and will still further increase the condensing effect. This

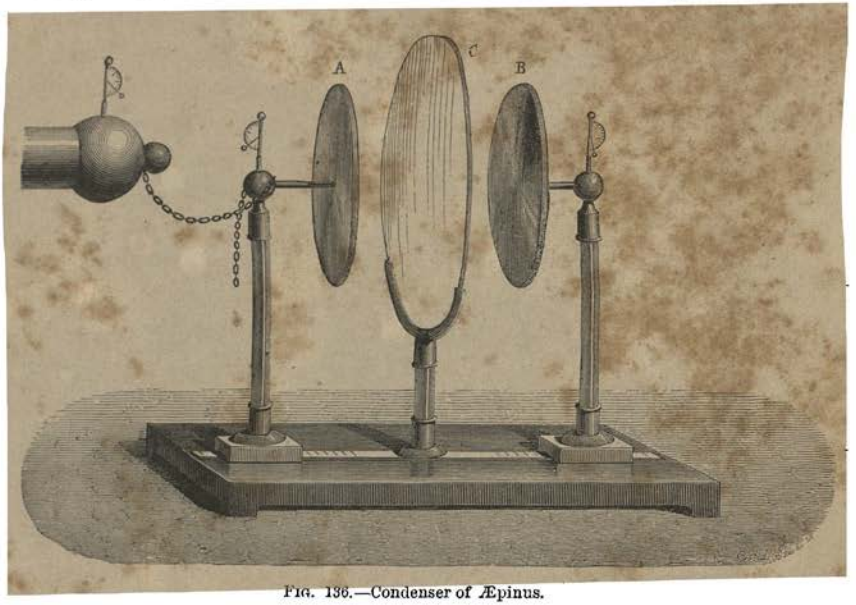

FIG. 136.—Condenser of Æpinus.

series of operations can be repeated several times, until the maximum condensing or accumulating effect has been attained on each plate.

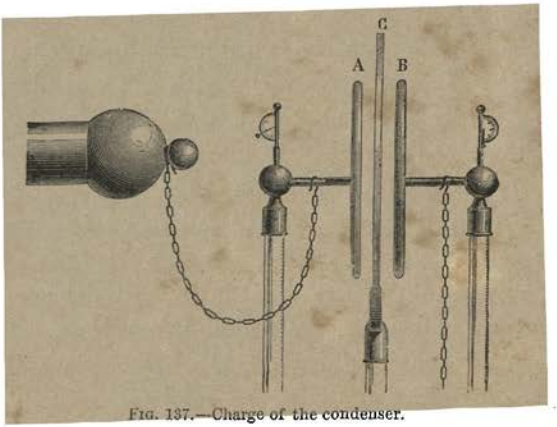

FIG. 137.—Charge of the condenser.

The action of these two opposite charges on any third or exterior body is *nil*, because they just balance each other. The charges on

both plates of a condenser in this state are said to be "*bound*." The following experiment proves that these charges are however in their ordinary state, and that they each act on any point situated between them. If either of them be touched on its inner face with a proof plane it will be found to be electrified with the same electricity as the rest of the body. It is now quite clear that the Leyden jar and Æpinus's condenser are really the same thing, but differ only in form; and that the phenomena observed in a certain order in one occur in the same order in the other.

But now what part does the glass plate play? Theory and practice both show that a layer of any insulating material will work; a plate of air, for example, between two conductors will show the same phenomena; but the air offers less resistance than glass to the electric stress that is excited across the medium, and would give way under that stress, being mechanically unable to resist being penetrated by a spark which would leave the whole apparatus immediately discharged. It is therefore necessary to use a body having the mechanical property of resisting the stress, such as glass or resin.

A most pregnant experiment due to Franklin throws some fresh light on the matter. A Leyden jar is made with movable coatings, so that each part can be separated from the other (Fig. 138). The jar is put together and charged; it is then placed on an insulating stand, and the inner coating is removed either by a glass hook, or by simply lifting it out by hand. If lifted with a glass hook out of the jar no electricity is found on this coating. Now remove the jar. It is found that the outer coating also possesses no charge. To make quite sure, both the coatings may be touched with the hand; this will effectually discharge them. We now know that both coatings have no charge; but if the jar be then put together again, on discharging it we shall obtain a spark just as brilliant as if the coatings had never been removed. It is perfectly clear then that when we charge the jar *we really charge the dielectric* and not the coatings of metal.

The residual secondary sparks were formerly believed to prove that the electricity penetrates slightly into the surface of the glass. The modern view of Maxwell is that the glass does not at once recover from the electric stress to which it has been subjected, just as a bent spring when released does not always fly back to exactly its

original position, but often retains a slight residual bend from which it slowly recovers. Maxwell attributed the residual recovery of the glass of the Leyden jar to the heterogeneity of its structure; it consisting, as is well known, of a mixture of silicates of lime, soda, or lead, in various proportions.

The following points may in conclusion be mentioned:—

The condensing force of the jar is greater the thinner the glass; but we must not reduce the thickness of the glass too far, because the jars are sometimes pierced by the electric discharge passing from one coating to the other through the glass. The thickness of the glass

FIG. 138.—Leyden jar with movable coatings.

should be sufficient to prevent rupture on the occurrence of a sudden external discharge; for if the jar be too highly charged, it sometimes discharges over the outside from the rod along the exterior surface of the glass. It is very important that the glass should be nearly uniform in thickness and have no bubbles; if there are any, discharges are produced at the spot where the resistance is small, and the bottle may be pierced. The nature of the glass greatly affects the result. Certain kinds of glass are slightly conducting: with these, according to Mascart, the electricity penetrates to a certain depth and the jar is not completely discharged at once; then several residual sparks can be obtained.

§ 3.—*Various Experiments with Leyden Jars and Batteries of Jars.*

The Leyden jar can be discharged either instantaneously or gradually without the slightest fear of the operator receiving a shock. To discharge a jar instantly, *discharging tongs* are used, consisting of two metal arms jointed together at one end, the other ends being furnished with knobs; the tongs are provided with glass handles (Fig. 139). To discharge a jar, one knob is first made to touch the

FIG. 139.—Discharge of Leyden jar with the discharging tongs.

outside coating; the other knob is then brought near to the knob of the jar, when a discharge will take place through the tongs.

Successive discharges are sometimes made to ring bells, as in Franklin's electric chimes (Fig. 140). The arrangement consists of a small pendulum made of an insulating thread with a metal ball at the end. The pendulum is held upon a metallic support, which is in connection with the outside coating of the jar; the rod from the inner coating of the jar is surmounted with a bell against which the pendulum strikes, and on the same level there is a bell on the metal stand. The ball is first attracted and then repelled from each bell in

turn, thus carrying over a small portion of each charge each time, until both jars are completely discharged.

Sometimes the pendulum ball is made like a spider, the legs being threads of silk, in reminiscence of a curious experiment made by Franklin.

That famous experimenter about the same time designed another curious piece of apparatus, by which two oppositely charged jars set up a movement of rotation.

He thus describes it at page 31 of his *Experiments and Observations*: "A small upright shaft of wood passes at right angles through a thin round board, of about twelve inches diameter, and turns on a sharp

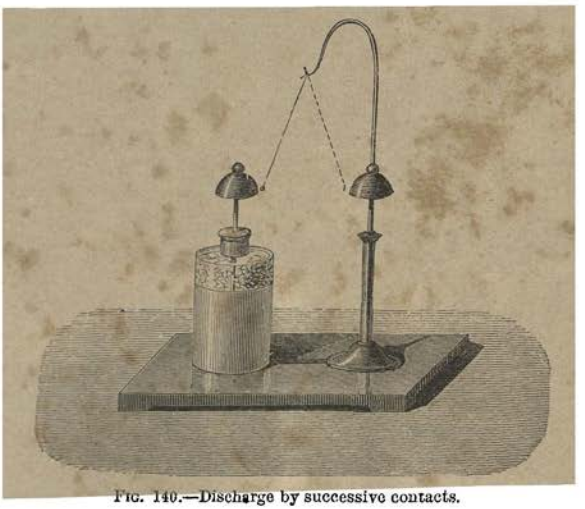

FIG. 140.—Discharge by successive contacts.

point of iron fixed on the lower end, while a strong wire in the upper end passing through a small hole in a thin brass plate keeps the shaft truly vertical. About thirty radii, of equal length, made of flash glass cut in narrow strips, issue horizontally from the circumference of the board, the ends most distant from the centre being about four inches apart. On the end of every one a brass thimble is fixed. If now the wire of a bottle electrified in the common way be brought near the circumference of this wheel, it will attract the nearest thimble and so put the wheel in motion; that thimble, in passing by, receives a spark, and thereby being electrified is repelled, and so driven forwards; whilst a second being attracted approaches the wire, receives a spark,

and is driven after the first, and so on until the wheel has gone once round, when the thimbles before electrified approaching the wire, instead of being attracted as they were at first, are repelled, and the motion presently ceases. But if another bottle which had been charged through the coating be placed near the same wheel, its wire will attract the thimble repelled by the first, and thereby double the force that carries the wheel round; and not only taking out the fire that had been communicated to the thimbles by the first bottle, but

FIG. 141.—The sparkling jar.

even robbing them of their natural quantity, instead of being repelled when they come again towards the first bottle, they are more strongly attracted, so that the wheel mends its pace, till it goes with great rapidity twelve or fifteen rounds in a minute, and with such strength as that the weight of one hundred Spanish dollars, with which we once loaded it, did not seem to retard its motion. This is called an electrical jack; and if a large fowl were spitted on the upright shaft, it would be carried round before a fire with a motion fit for roasting."

The experiment of the sparkling jar (Fig. 141) will serve to show how in the sudden discharge the electricity comes converging from all over the surface of the glass to the point where discharge is effected. In this the exterior coating is made like that of the sparkling square (Fig. 130), of pieces of foil or tinsel stuck on with gum. To the interior coating is fixed a tongue of foil stretching over the shoulder to within a very short distance of the edge of the outer coating. As soon as the bottle is sufficiently charged sparks glide in serpentine

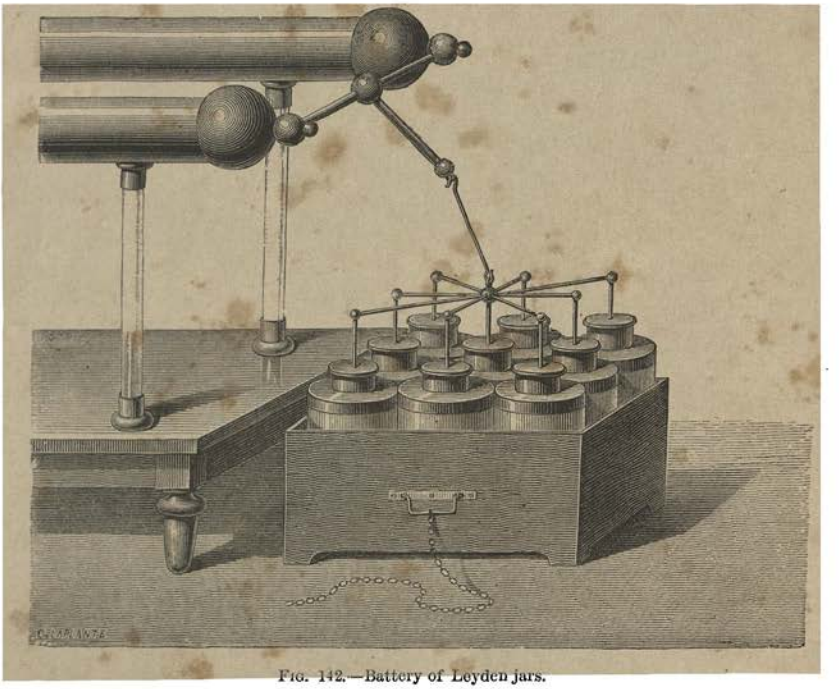

FIG. 142.—Battery of Leyden jars.

lines of fire over the outer surface, along paths meeting in the point where the discharge commences.

To produce more energetic shocks and sparks jars of larger size are used. A bottle with a wide neck is chosen, so that the inside like the outside can be covered with tinfoil. When several of these jars are place together in a box, all the exterior coatings being connected, and also all the interior coatings, as shown in Fig. 142, the arrangement is called a *battery of jars*. To charge this arrangement the

interior coatings are connected by the knobs to the machine. All the exterior coatings are connected together by being in contact with the tinfoil lining of the box, and this in its turn is connected to the earth by a chain.

The charge contained by such powerful condensers as these is enormous, and it takes some time to charge them fully when using an ordinary machine.

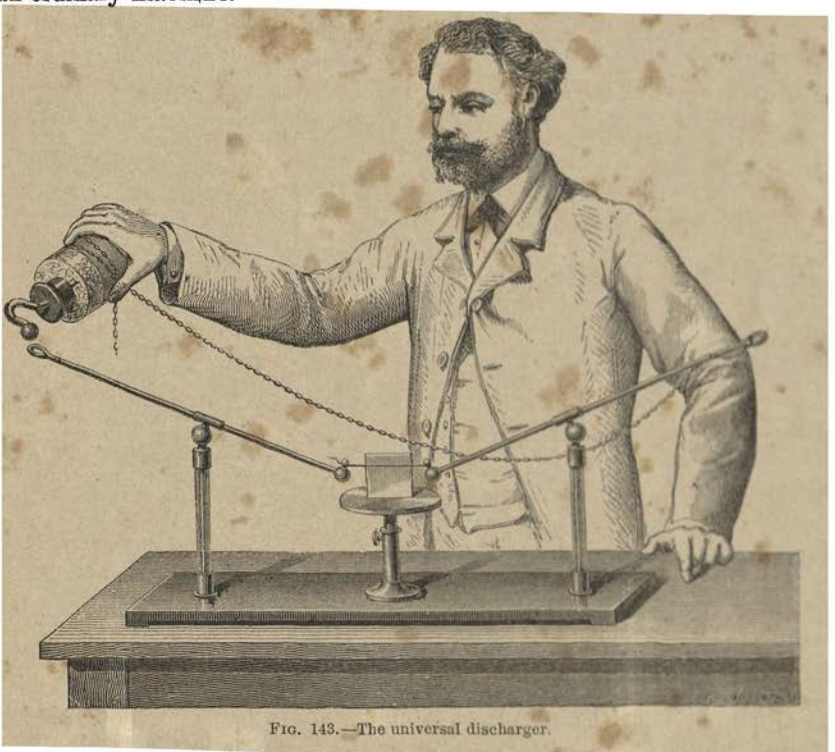

FIG. 143.—The universal discharger.

A battery of jars may also be charged more rapidly by arranging them *in series*, the inside coating of one being connected to the outside of the next, and so forth. But the advantage gained is imaginary, as the electromotive force of the machine is now divided between the jars. If there are ten jars in series, each gets only one tenth of the electromotive force of the machine. Franklin called this method charging "*in cascade*."

The discharges of a battery are more or less dangerous, according to the number of jars and their size. A battery of six jars of average

size is sufficiently powerful to kill certain animals, such as rabbits or dogs. Thus it is necessary to use great care whilst handling large batteries, and it is advisable to use the apparatus which is called the *universal discharger* for this purpose. This consists of two brass rods, each terminated at one end by a ring, and the other end by a knob; each rod is insulated upon a glass support and slides through a ball-and-socket joint. Between the supports carrying the rods is a small insulated table upon which is placed the object to be subjected to experiment. A chain is put into connexion with the earth from the ring of one rod, whilst the other rod is connected to one limb of the

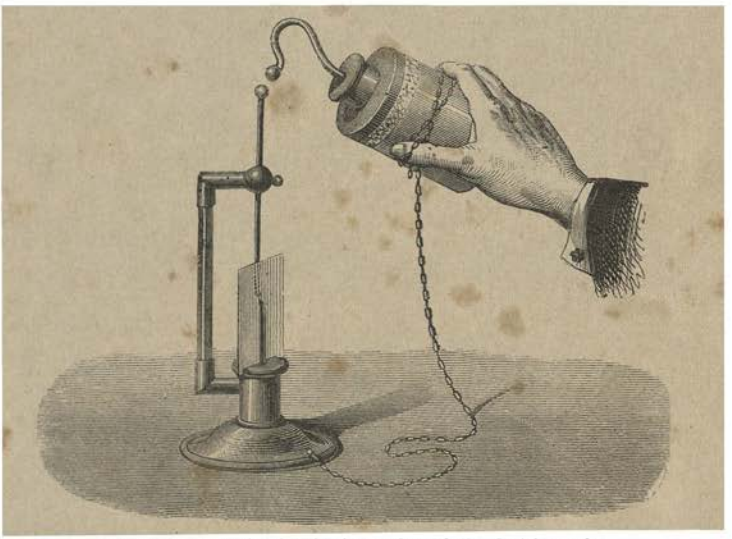

FIG. 144.—Apparatus for piercing cards with the electric spark.

discharging tongs by means of a chain, the other end of which is brought into contact with the knob of the battery. The experiments which follow show the different mechanical and physical effects of electricity accumulated in condensers.

In the experiments upon the electric mortar and upon Kinnersley's electric thermometer, we have already seen some of the mechanical effect of the disruptive discharge. The molecules of matter are violently displaced in the body through which the discharge takes place. This is well illustrated by making the spark pierce a card or glass. For this purpose a card requires to be placed between two points which are brought opposite each other; one of the rods requires

to be insulated. The outer coating of a jar is now attached to the non-insulated rod, and the knob is brought near the insulated rod, when a spark passes between the points and the card is pierced. In air the hole is nearer to the negative point than the positive, whilst it is not so in a vacuum. We can scarcely explain how this occurs. It is remarked that the edges of the hole are burred on each face of the card, the discharge apparently beginning in the centre of the card and working its way outwards. Possibly the heat generated in the card will account for this. In the same way glass of ·5 or 1·0 millimètre

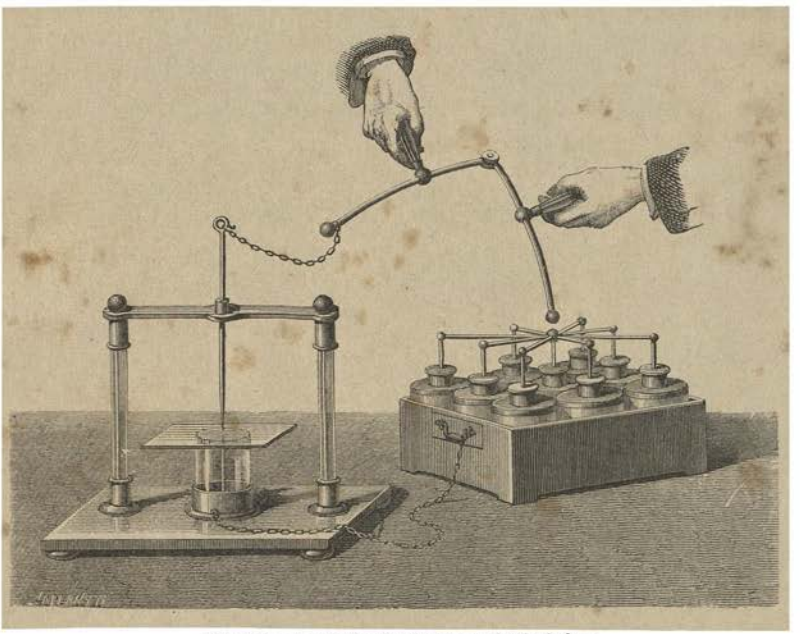

FIG. 145.—Apparatus for piercing a sheet of glass.

thickness, when placed horizontally between two points, as in Fig. 145, can be easily pierced. Care must be taken not to allow the electricity to spread over the surface of the glass; this can be prevented by dipping the metallic points in oil. After the discharge there is a small round hole through the sheet, the glass at that point having been finely powdered. To make this experiment successful it is necessary to use a large battery. If, under these circumstances, the glass be not pierced the surface is found to be altered and roughened where the spark took place.

The heating effects of the electric discharge are not less interesting than the mechanical effects. If the two knobs of the universal discharger (Fig. 143) are joined by a piece of very fine metal wire, gilded silver for example, the wire is heated, becomes incandescent, and is melted or volatilised according to the amount of charge. With powerful batteries such as that belonging to the *Conservatoire des Arts et Métiers* in Paris, or to the Royal Institution in London, pieces of wire several mètres long have been melted. If the wires are of the same size and of the same length but of different metals, different charges are required to melt them; iron, lead, or platinum melt much easier than gold or silver, or above all copper. Fusion takes place easier if the discharge is in air than it does if the discharge is in a vacuum. If the knobs of the universal discharger are joined by a piece of gilded silk the discharge will melt the gold but will leave the silk unbroken.

The particles of volatilised metal can be collected on a piece of white card, against which the thread is made to rest before the experiment. On the card is seen a blackish film, formed by a fine powder of volatilised gold. By using various metals various coloured films can be obtained, and if the metals used are oxidisable at high temperatures the films obtained are formed by the metallic oxides reduced to an impalpable powder. Van Marum made, towards the end of the last century, some very fine experiments on the transport of metals by the electric discharge. Fusinieri, having passed a discharge between the two balls, one of gold and the other of silver, observed that the first was silvered and the other gilded at the points where the spark passed. It is probable that the phenomena that we have just described are complex, and are due partly to the elevation of temperature produced by the discharge, and partly to the mechanical carrying of the molecules.

This property has been made use of in reproducing various designs in metallic films. The usual experiment in lectures is the production of Franklin's portrait. Fig. 146 shows a thick sheet of paper from which is cut out a portrait of that illustrious physicist; sheets of tinfoil are placed right and left of the paper. On the top is placed a sheet of gold leaf, and underneath a piece of white silk is placed against it. After having folded down over the gold leaf the leaves of the paper seen above and below the portrait, the whole is placed

in a press (Fig. 147) and is screwed up tightly; it is now placed in position between the knobs of the universal discharger. When the knobs are in contact with the strips of tin, which stick out each side, a charge is passed through. The gold is volatilised and forms a

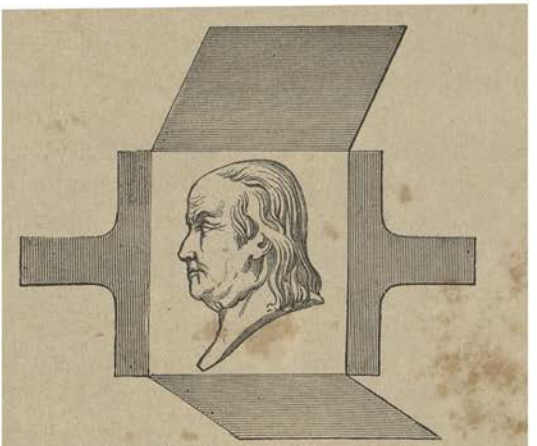

FIG. 146.—Experiment of Franklin's portrait.

blackish film on the silk, the shape of the part cut out of the paper; thus the pattern is copied by electricity.

At the date of Franklin, when photography was as yet quite unknown, this method of producing portraits was regarded with great wonder and interest.

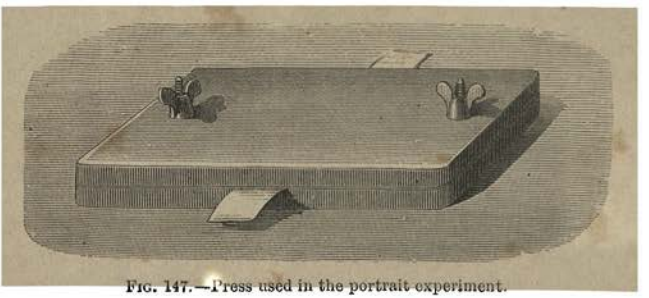

FIG. 147.—Press used in the portrait experiment.

The fusion of metallic films is a certain proof of the rise in temperature which accompanies the electric discharge when it passes through a conductor. Disruptive discharges through an insulating medium are accompanied with a spark showing heating effect. Combustible

materials, such as gunpowder or ether, can be set fire to by passing a spark to some part of the substance. This experiment can be performed in the following way: Let some person stand on an insulating stool and place one hand on the conductor of a machine,

FIG. 148.—Volta's pistol; sectional view.

and let him hold in his other a metallic point near to a small dish of ether, which is held by some other person. The liquid will be set on fire by the sparks. Watson set fire to ether by a spark from a lump of ice.[1]

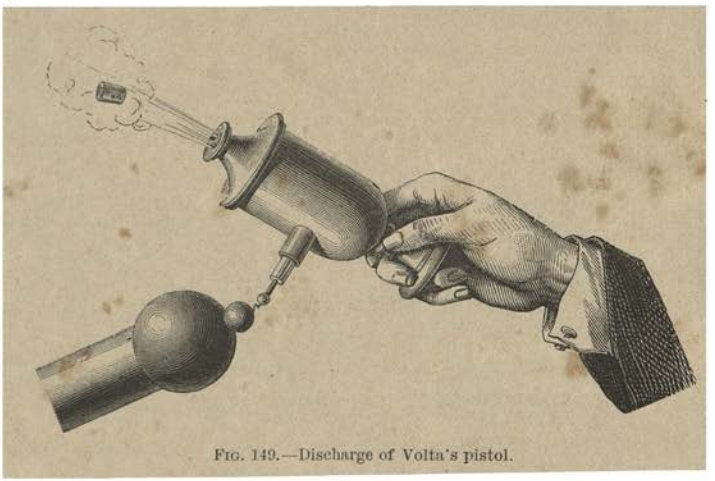

FIG. 149.—Discharge of Volta's pistol.

The electric spark produces very interesting chemical effects. If a spark be passed through an explosive mixture of oxygen and hydrogen, it is ignited instantaneously. Volta's pistol is based on this experiment. Figs. 148 and 149 show a section and an exterior view

[1] The experiment rendered thus more striking is not more strange than that of setting fire to a piece of tinder by means of a double convex lens of ice.

of this apparatus. It consists of a hollow metal vase closed by a cork, and is filled with a mixture of oxygen and hydrogen gases. A brass rod with a knob at each end enters the vase near the base, but is insulated from it by an ivory tube. The vase is put into connection with the earth, and the exterior knob of the rod is brought near to the conductor of a machine. The two gases combine with an explosion and the cork is blown out to a considerable distance.

The electric spark produces innumerable chemical reactions, among which we may name the formation of nitric acid from oxygen and nitrogen, the synthesis of water; also ammonia is decomposed in

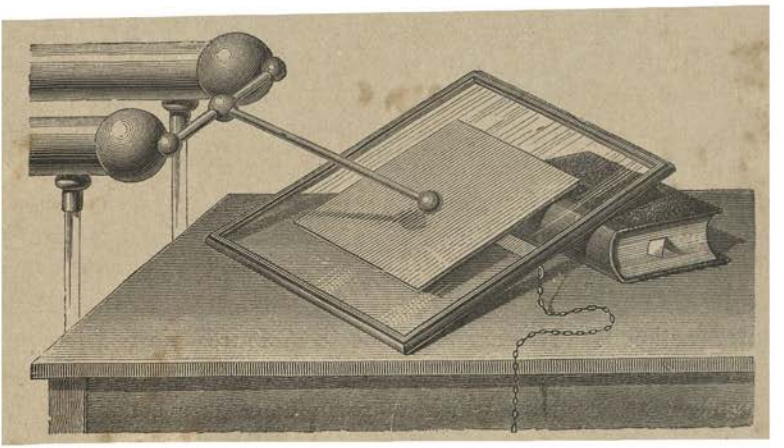

FIG. 150.—The fulminating pane.

a eudiometer tube. Many of these reactions can also be produced under the action of the silent discharge from points. We have already alluded to the effects of the discharge when it passes through the human body, or through animals. The effects are the more marked when they are produced with a more powerful apparatus. We have already said that it is dangerous to receive a discharge from even a very small number of Leyden jars.

A very interesting and pretty experiment is to take a square of glass and to paste on each side, and opposite each to other, two squares of tinfoil, one of them being insulated, the other being connected to the framework and thence to the earth. A coin, such as a shilling, is laid on the insulated foil, which is then put in connexion with a

machine and is charged. Whilst now charged, if anybody try to pick up the coin from the insulated surface he will receive a shock that will make him drop the coin in haste.

§ 4.—*Electroscopes and Electrometers.*

Having described various apparatus for producing electricity, and also some experiments to illustrate its properties, we must now describe some instruments used in its detection and measurement.

The name *electroscopes* is given to instruments which serve to distinguish, in the first place, whether a body is electrified or not, and secondly, the nature of the electrification on its surface. The simple and double pendulums, consisting of pith-balls on silk strings, are sometimes called electroscopes. The name *electrometers* is given to instruments used for measuring the quantities of electricity on bodies, or for measuring differences of electric potential that subsist between them. Coulomb's torsion balance, which we have previously described in connection with the determination of the laws of electric action, is an electrometer, as it measures electric forces.

The *simple electric pendulum* consists of a cork-ball or pith-ball suspended by a thread, which, in some cases, is a conductor, sometimes an insulator. When the thread is a conductor, and in communication with the earth by a metallic stand, the apparatus simply indicates, by being attracted, whether the body held near it is electrified or not. If the suspension thread is of dry silk, and the stand is glass varnished with shellac, the instrument will then show differences of electrification. To show this, an electrified body is brought near the ball, which is first attracted, and after contact is repelled. This being done, if a stick of glass and a stick of sealing-wax are electrified by rubbing them with a piece of cloth, and bringing them alternately near the ball, one will be attracted and the other repelled. We might proceed in an inverse way by electrifying the ball by making it touch one or other of the rods. When electrified by a glass it would be charged positively; by the resin, negatively. If the body with which we are experimenting repels the pendulum ball, they are obviously both electrified in the same way.

The *double pendulum* consists of two pith-balls, suspended by cotton threads, and they hang together when they are not electrified, but repel each other when electrified. Dufay used this form in 1733; and it was later employed by the Abbé Nollet, by Cavendish (1781), who measured the amount of electrification by the degree of divergence of the two balls, and by John Canton.

Henley's semaphore electroscope and the gold-leaf electroscope are respectively examples of a simple and of a double pendulum. Figure 151 represents the first of these apparatus, which was at one time mis-named the quadrant electroscope. It consists of a metal or wooden support with a semicircular ivory scale. At the centre of the scale is hung a light rod with a pith-ball at the end. When this apparatus is placed on a charged body, the electricity spreads over all parts of the electroscope. The pith-ball, at first in contact with

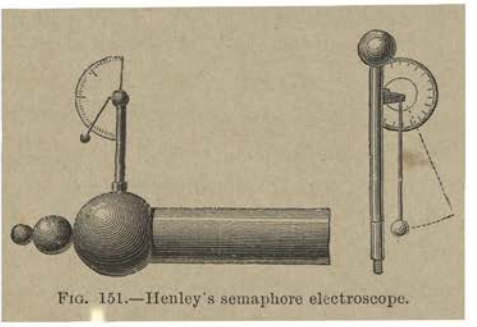

FIG. 151.—Henley's semaphore electroscope.

support, is repelled, and its deviation from the vertical is shown by the divisions of the scale, the angle becoming larger as the charge on the body increases.

The gold-leaf electroscope (Fig. 152), invented in 1786 by the Rev. Abraham Bennet, consists of a bell glass placed on a metal stand; through an opening in the top passes a brass rod, which is surmounted by either a knob or a metal plate. The metal rod carries on its lower end two pieces of gold leaf, which, when there is no charge in the apparatus, hang vertically in contact with one another, but diverge when the apparatus is charged. The following is the way to use a gold-leaf electroscope when one wishes to determine whether a body is electrified or not.

The body to be tested is gently brought near to the exterior knob; if it is not charged the leaves remain together. If on the

contrary it is electrified, positively for example, the system consisting of the knob, the rod, and the gold leaves is disturbed. Its natural electricity is repelled to the lower part, causing a positive charge on the gold leaves, and leaving the upper part, the knob, negatively charged. The gold leaves at once diverge, forming an angle, which varies with the inducing charge, but not in exact proportion to it. This experiment will indicate the presence of a charge of electricity, but conveys no information as to its sign: for, whether the charge be + or −, there will equally be a mutual repulsion between the two gold leaves.

The following is the more usual mode of procedure if it is desired

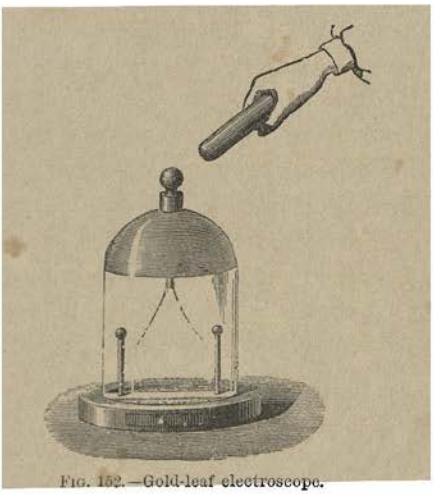

FIG. 152.—Gold-leaf electroscope.

to test the sign of the charge. The electroscope is first charged itself from some known source, and usually by the inductive method: that is to say, it is touched while under influence. A convenient known source is a stick of sealing-wax or of ebonite, rubbed by a cat's skin. The charge of the stick is a negative one. Then if the charged stick is held near to, but not touching the knob, its influence causes a charge in the electroscope. A positive charge results at the nearest part, the knob and the leaves are left relatively negative; the negative being (as we have seen) apparently repelled to the furthest part. Then, while the influencing charge is still held near the knob, the knob is touched with the finger of the experimenter. This

touch, which momentarily connects the gold leaves to earth, neutralises their negative charge, and they drop down side by side. But the touch did not remove the positive charge on the knob: that being "bound" under influence of the neighbouring negative inducing charge. So if finally the influencing charge be removed the electroscope is left with a positive charge which now distributes itself over knob and leaves, which once more diverge. We know now that the electroscope is positively charged, and are ready to test any electrified body by means of it. If the body to be tested is positively charged, then, when it is brought near to the already positively charged electroscope, the gold leaves will open out still more widely. If the body be negatively charged it will, on the contrary, cause the leaves to approach one another so long as it is near. It must be remarked, however, that any non-electrified conductor held near will have the same effect of making the leaves drop, so that the increase of repulsion is the surer sign. If we had wanted to charge the electroscope negatively instead of positively at first, we must have begun with a positively charged instead of a negatively charged body: for it will be remembered that the operation of touching a conductor under influence always leaves the touched thing electrified with a charge of opposite sign to that of the inducing body.

On either side of the leaves of the electroscope are shown two metal pillars, terminated by knobs; these rods are fixed to the base board of the apparatus, and are in connection with the earth, and become electrified by induction in the opposite way to the leaves, which they therefore attract, thus causing an increase in their divergence.

If the divergence be sufficient for the leaves to touch the sides of the glass shade, they are brought into contact with the metallic knobs, which at once discharges them, and therefore they at once fall together again. Thus the difficulty of the leaves sticking to the glass is averted.

When the body, the charge of which we wish to determine, is only electrified to a very slight extent, it is often found impossible to get an appreciable divergence of the leaves; in this case Volta's *condensing electroscope* is used. This is an ordinary electroscope having a disc of metal, carefully coated on its upper side with shellac

varnish, in place of a ball. Upon this disc is placed another disc of the same size furnished with an insulating handle varnished like the first, but on its under side, so that the two insulated faces touch one another. Now let us suppose that it is desired to study the electric condition of a very feeble charge; for example, that existing on a double rod of copper and zinc. The top plate is put into connection with the earth by touching it, as shown in Fig. 153; then taking the rod by the zinc end and touching the lower condenser plate with the copper end the two plates are charged, the charge accumulating by induction. The two plates are broken when the electricity of the lower plate, which was held at the surface,

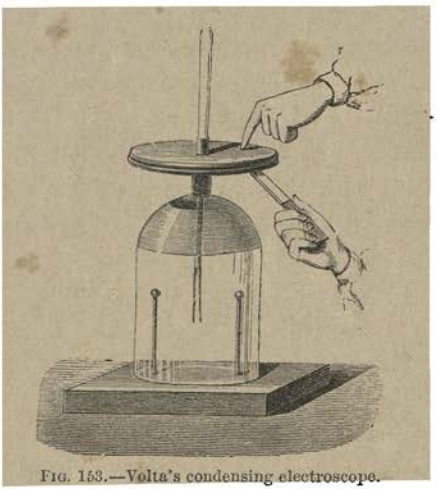

FIG. 153.—Volta's condensing electroscope.

spreads over the lower plate and to the gold leaves, causing them to diverge. Volta succeeded in observing very small charges; those which without the condenser only gave 0°·25 gave with it 30°, or were increased 120 times.

Sir Wm. Thomson has designed various forms of electrometers; those most used and most exact are called *quadrant electrometers*, represented in Fig. 154. We will now explain the principle of them.

A very light metal "needle" made, for example, of aluminium, having the form of a figure 8, as is seen represented at C, Fig. 155, is suspended by two thin parallel wires, so that it can oscillate in a horizontal plane like the needle of a compass. To this needle is imparted a strong electric charge, and in order to avoid the loss this

charge might undergo it is connected by platinum wire to a Leyden jar. The jar is itself an inverted, bell-shaped vessel of glass, partly filled with pure concentrated sulphuric acid, which forms the inner coating; it is covered outside with strips of tinfoil which form the exterior coating of the jar. The needle is inclosed in a kind of box formed of four metal quadrants arranged horizontally as in Fig. 155. Each quadrant is insulated from its neighbours, but connected by a

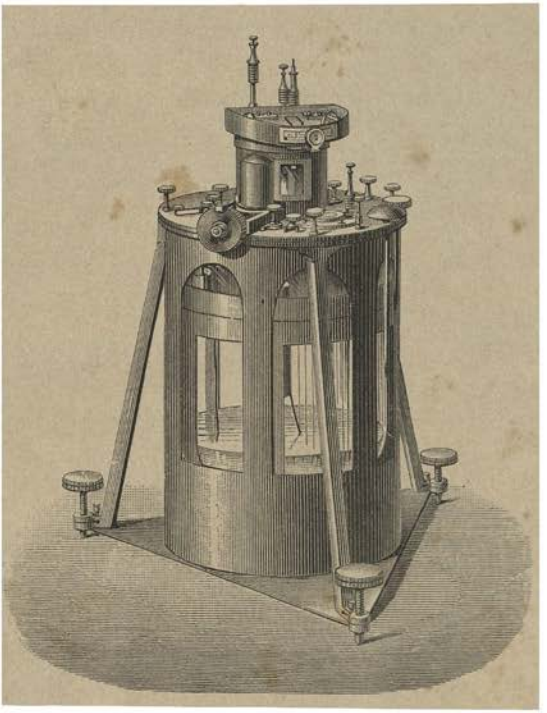

FIG. 154.—Sir W. Thomson's quadrant electrometer.

wire to the one immediately opposite, the whole thus electrically forming two separate systems.

Let us suppose the needle to be charged with a positive charge of electricity, then put the quadrants A A′ in communication with the earth, and the opposite quadrants B B′ with the conductor, the electric state of which is desired to be ascertained. Some of the electricity of the conductor will flow to the quadrants B B′ or *vice versâ*, and will charge them so that they are either positive or

negative, as compared with the other pair of quadrants A A′. The needle will then turn, each of its ends being more attracted by the pair of quadrants which is more highly negative, and will be less attracted by the other pair. The direction of the deflection will

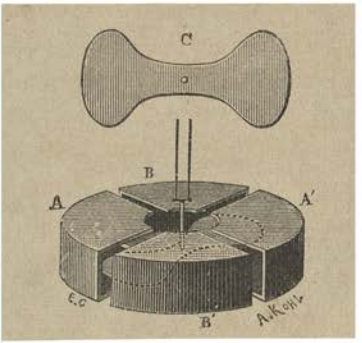

FIG. 155.—Needle and quadrants of Thomson's electrometer.

show then the electrical state of the conductor that has been thus tested, and the amplitude of this deflection will measure its relative potential. As the deflections observed are not usually more than a

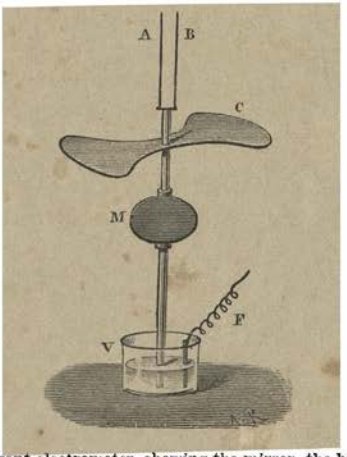

FIG. 156.—Needle of quadrant electrometer, showing the mirror, the bifilar suspension, and the connexions for charging the needle.

very few degrees, recourse must be had to the optical method of reading them. Accordingly there is fixed upon the stem of the needle a little concave silvered mirror, M (Fig. 156), in which you observe the reflected image of the divisions of a graduated scale.

In Fig. 154 it may be noticed that above the lid of the box that incloses the Leyden jar, and above the system of quadrants, there is a "lantern" within which is the point of suspension of the stem of the needle. Through the opening of this lantern is seen the little mirror fixed above the needle, not underneath, as might be thought by the theoretic arrangement of Fig. 156.

We confine ourselves to these summary notes, referring the reader to special treatises for the detailed description of Sir William Thomson's electrometers, of which many different patterns exist.

The charge of electricity furnished by a machine to a conductor may be roughly measured by the intensity of the spark produced at the discharge, or by the number of sparks of given length required to complete the charge or discharge. Lane's spark electrometer is an apparatus based on the latter principle. It is formed of a Leyden jar, the interior coating of which communicates with the source the charge of which is to be measured. The exterior coating communicates on its side with the earth and with a ball supported by a vertical pillar, and which can, at will, be brought near the ball *a* by aid of a screw supporting the stem and moving the pillar. If a proper distance has been fixed between the two balls, then when the potential of the electric charge (supplied from an electric machine, for example), has reached a certain limiting value, a spark will jump across, thereby discharging the jar. If the action be repeated again and again, it is clear that the total quantity of electricity which thus flows is proportional to the number of sparks produced between the balls of the apparatus. But in order to compare the quantity thus supplied from different sources, the distance at which the spark passes must remain the same. If the distance between the balls is widened the jar must be charged to a higher potential before a spark will leap across.

In measuring the charge of a Leyden battery by means of Lane's electrometer, or by Harris's unit jar, which is a modification of it, the operation can be made in two different ways: (1) Insulate the battery; join its internal coating to the generating machine, its external coating to the knob *a* of the spark electrometer, the knob *b*, as well as the exterior coating of the bottle, communicating with the ground. As the battery becomes charged with a positive charge, its exterior coating acquires a corresponding negative charge, and the jar

of the electrometer is also positively charged. (2) Insulate the jar of the electrometer; put the knob *a* into communication with the machine, the knob *b* being connected to the inside of the battery, the outside of which communicates with the ground. In the one case you measure the charge of the battery by the number of sparks of charge flowing out of its outer coating; in the other you measure it by the number of sparks that flow (at the same difference of potential) into its inner coating.

[The modern way of measuring the quantity of charge in any condenser is to measure separately the capacity of the condenser, and the potential to which the charge in it has risen. The product of

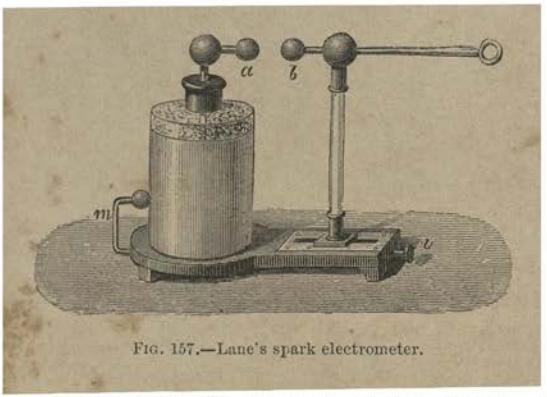

FIG. 157.—Lane's spark electrometer.

these two quantities gives the amount of the charge. The electric capacity is measured by comparing it with the capacity of some standard condenser, for example, of a standard condenser of one microfarad capacity. The potential may be measured by the quadrant electrometer. Or, lastly, the quantity of the charge may be measured directly by discharging it through a special "ballistic" galvanometer, and observing the first swing of its needle.

§ 5.—*Effects of Electric Discharges.*

When a body is charged with electricity it can be brought back to its natural state in two ways. *Firstly*, you may put it into communication with the earth by means of an intermediate conducting body, for example, a metal wire; in this case there is a current momentarily set up in the wire, either from the body to the earth or

from the earth to the body. This kind of discharge received from Faraday the name of *conductive discharge. Secondly*, you may discharge the body by bringing near its electrified surface another conducting body, but without there being any contact; in this case discharge takes place through the interposed insulating medium, the air, by the production of a spark, and this is called a *disruptive discharge.* The effects which result from these two modes of movement of electricity are very varied; we have already given some examples in the different experiments above described. It is best to complete them.

The effects of the discharge of electric charges may be classed in three principal categories: *mechanical and physical effects, chemical effects,* and *physiological effects,* according to the nature of the phenomena which then show themselves; but it happens often that these effects are produced simultaneously.

We will begin with the *mechanical effects.* The experiments of piercing a card and piercing glass have shown us the spark traversing solid bodies of small thickness. It is not so much the quantity of electricity that matters as the difference of potential.

This expression, "difference of potential," which we have already used one or twice, requires to be explained. We cannot do better, in order to give a clear and precise idea of its meaning, than borrow the following explanation from a treatise from which we have already quoted several times. "Whenever electricity moves, or tends to move, from one place to another, there is said to be a '*difference of potential*' between those two places. The place from which positive electricity tends to move is said to be of higher potential than the other. Suppose a quantity of electricity to flow from the one point to the other, then the 'difference of potential,' or, as it is also called, the 'electromotive force,' between these points is a quantity which expresses the amount of work which each unit of the electricity could do on its journey if it were all utilised by being passed through some perfect machine of which it formed the motive power. Difference of potential is calculated as follows:—Let a unit of electricity be forced from one place to the other in the opposite direction to that in which the electric forces tend to move it; mechanical work will have to be done on it by a man, a steam-engine, or other source of power. The difference of potential between

any two points is defined to be numerically equal to the amount of work required to force a unit of electricity from the one point to the other, in the direction opposed to that in which it tends to move."[1]

If difference of potential is thus a measure of the tendency to move electricity, one would expect to find a direct relation between the power of an electric charge to pierce through a piece of glass and the difference of electric potential between the front surface of the glass and the back surface.

"It is thus," says Mascart, "that a plate of glass some millimetres thick can be pierced as well with one jar as with a battery, or even more easily. The direct sparks of an electric machine suit better because they are longer; that is to say, though there is a smaller quantity of electricity in them than in the snapping spark of a Leyden jar, that smaller quantity is at a higher potential. The sparks from a Holtz's machine succeed better still, because in these machines the two jars are arranged 'in cascade,' so that the difference of potential is very great." It is possible thus to pierce plates several centimetres thick; but care must be taken to prevent the spark from following the surface of the plate by going round it instead of through it.

Van Marum burnt in two a cylinder of boxwood 8 centimetres ($3\frac{1}{2}$ inches) in diameter, and the same in height. He thrust into the ends the two points of the discharger joining the poles of a battery of jars having 15 square metres of surface.

A very singular mechanical effect, observed first by Nairne, and which Becquerel afterwards studied, is the shortening which the discharge of a battery produces in a metal wire which it traverses; for compensation there is a slight increase in the diameter of the wire. If the discharge passes between two metal bodies, for example between the brass knob of a Leyden jar and a plate of silver, it causes on the plate a little yellow spot, due to the transport of detached particles of the knob. May not this carrying of metal be due to the volatilisation of the metal which results from the rise of temperature produced by the spark?

This question leads us to say a word on the heating to which an electric discharge, whether conductive or disruptive, gives rise.

[1] Gordon, *Electricity and Magnetism*, p. 26.

When the discharge of a battery is passed through a conducting wire, the wire is heated; but the elevation of the temperature depends both upon the quantity of electricity conveyed and upon the resistance that the wire offers to the passage of electricity; and that resistance itself depends on the size of the wire, and the nature of the metal which constitutes it. For the same discharge of electricity the quantity of heat set free is proportioned to the length of the wire, and in inverse ratio to its section, provided the wires are of the same material. But if different metals are used, the elevation of the temperature is found to be in inverse ratio to the specific heat of the metal, and to its electric conductivity.[1]

If the metal wire is fine enough, and the power of the battery sufficiently great, the temperature may be raised to that of fusion of the wire, or it may even be volatilised. We have seen before how the experiment is arranged in using the universal discharger (Fig. 142), and we have already pointed out some of the effects obtained by employing wires of different metals. We will add that this property of electric discharges has been used to measure their comparative amounts, and it has been found that the longest length of a given wire which the discharge can bring it to the temperature of fusion, without going beyond it, is directly proportional to the square of the quantity of electricity in the charge, and inversely proportional to the total surface of the battery. All metals are not equally good for experiments: brass, for example, does not do, because it softens before the point of complete fusion. Iron and steel, on the contrary,

[1] The metals may be arranged in a series in which one of them, platinum for example, being taken at 1, each metal is characterised by numbers measuring its specific resistance, its co-efficient of heating, and its resistance to fusion. The following table is the result of experiments on this subject due to Riess.

Metals.	Specific Resistance.	Co-efficient of Heating.	Resistance to Fusion.
Copper	0·1552	0·1133	4·893
Silver	0·1045	0·1267	3·946
Gold	0·1746	0·2112	2·960
Iron	0·8789	0·7080	1·059
Platinum . . .	1·	1·	1·
Nickel	1·180	0·8727	0·916
Cadmium . . .	0·4047	0·58	0·310
Tin	1·053	1·57	0·072
Lead	1·503	2·876	0·058

are excellent; these two metals fall in little drops as soon as the temperature of fusion is reached.

We will give Mascart's account of an example of the truth of the law of which we have just spoken. "If a battery is charged," he says, "by the intermediation of a Lane's unit jar, and if the sparking distance of this jar is regulated so that the battery charged with 50 sparks is capable of melting, say, 25 centimetres of iron wire of 0·1 millimetre in thickness, we should know that the successive charges of 40, 30, 20, 10 sparks are able to melt exactly the lengths of the same wire equal to 16, 9, 4, and 1 centimetres. Thus the limiting length of fusion of the same wire is exactly in proportion to the squares of the charges of the battery. The production of light, which accompanies the disruptive charges, is one of the most interesting of the physical effects of electricity. The various forms which the phenomenon takes—the lights, the brushes, sparks, their duration, their length, their intensity, the colour which they assume in the different media—deserve a separate study, which will be considered in a special chapter, when we have completed our review of the different means of obtaining electricity. We only wish here to speak of some of the physical or chemical effects with which electric light is accompanied.

The electric spark, when it is produced in contact with or near to a combustible substance may produce burning.

The philosophers of the last century made many experiments on this. We have already seen in Section 4 that alcohol and ether can be lighted thus; it is also possible to relight a candle when the wick still smokes, or to produce the explosion of a heap of gunpowder. In order that this last experiment should succeed certain precautions are necessary, at least if the spark comes from a strong discharge, that of a battery, for example. The powder must be mixed with another combustible body, one which is a bad conductor, as powdered resin, or camphor. The heat which results from the increased resistance is then sufficient to light the powder, which may be placed in a paper case between two metal points, each of which communicates with one surface of a Leyden jar.

The electric spark produces chemical phenomena—combination of gases, or decomposition of binary compounds, and of saline solutions. An experiment made in 1784 by Cavendish showed, for the first

time, that the so-called "inflammable air" or hydrogen, combines with the oxygen of the atmosphere to form water. This experiment is repeated now in chemical laboratories with an apparatus which has received the name of the *Eudiometer*. Fig. 158 represents the eudiometer with mercury. It consists of a glass tube terminated by a metal cap which ends in a metal knob. After having filled the tube with mercury it is inverted into a bath of the same liquid, and the two volumes of oxygen gas and two of hydrogen successively are put into it. A spiral wire is pushed up through the mercury in the tube, and goes up so as nearly to touch the inside of the metal cap.

FIG. 158.—Eudiometer. Spark used to produce combustion of oxygen and hydrogen in tube.

Things being thus arranged the plate of an electrophorus is brought near, producing a spark in the interior of the gaseous mixture. The mercury rises in the tube and leaves 1 volume of gas, which, on being tested, proves to be pure oxygen. The 2 volumes of hydrogen have combined with 1 volume of oxygen to form water, which is deposited as a film of moisture on the interior sides of the glass tube.

In this case the electric spark in passing through the layer of mixed gases merely causes an elevation of temperature sufficient to determine the combustion, that is to say, the chemical combination, of this layer. The ensuing heat of combination is propagated to the

neighbouring layers, and the whole mixture undergoes the same action; but for that the proportion of the gases must be suitable. According to Humboldt and Gay-Lussac no combustion of the explosive mixed gases occurs if oxygen is in excess in proportion of 14 to 3.

Among the examples of chemical combinations brought about by the aid of the electric discharge, we quote one from Berthelot. This eminent chemist succeeded in synthesising prussic acid by passing a series of discharges through a mixture of nitrogen and acetylene.

In the same way certain combinations also may be decomposed, for example, certain metallic oxides, several acids, and many compound gases. Sulphide of mercury, oxides of lead, zinc, tin, bismuth, carbonic acid, acetylene, carbonic oxide, hydrochloric acid, nitrous acid, and ammonia are decomposed into their elements when they are traversed by series of discharges or electric sparks.

As the last example of the chemical effect produced by electric discharges we shall quote *ozone*, a name given to electrified oxygen gas. Forty-six years ago a Swiss chemist, Schönbein, recognised in electrified oxygen characteristic properties, which since then have been objects of important study. Ozone has a very strong and somewhat unpleasant smell, resembling that which has been long remarked after the occurrence of a thunderstorm. If breathed in great quantity ozone irritates the mucus of the bronchial membrane and produces spitting of blood. Moist ozone oxidises most metals, decomposes organic colours, and decomposes idoide of potassium.[1]

"By the help of these characters of ozone," says Mascart, "it is easy to prove the presence of it in a great many electric experiments. The air which has passed between the plates of a Holtz machine is highly odorous. The brushes which issue from the edges and points of electrified conductors and the discharges of Leyden jars produce ozone in the air, and when a certain number of electric experiments has been performed in a closed room there is a so-called 'sulphurous' smell all around, which is in reality due to a small quantity of ozone." Even before Schönbein's chemical investigation and discovery others had noticed the presence of a characteristic agent.

[1] Ozone turns paper impregnated with iodide of potassium and starch blue. This property is made use of for measuring the quantity of ozone that atmospheric air contains.

Van Marum thought that this smell was the smell of electric matter; Franklin pointed out that it furnished an additional analogy between the electricity furnished by the machines and the electricity of the thunderstorm.

One of the most important of the physical effects produced by electric discharges is its action on a neighbouring steel needle. It can communicate to it magnetic virtue, or if the needle is already magnetised it can change its magnetic poles. It was Franklin who first discovered this means of magnetising little bars of steel; for this he used a Leyden jar. Kinnersley, having passed an electric discharge into iron wire, saw a magnetised needle spin round on its pivot at the moment when the discharge traversed the wire.

These facts acquired no real importance till 1820, when the Swedish philosopher, Oerstedt, discovered the influence on the magnetised needle of the currents of the voltaic battery. Later on we shall study these facts, which constitute a special branch of the science of electricity—*Electromagnetism.*

To complete this paragraph we have yet to describe the physiological effects of electricity. By this is meant the effects produced when the electric discharge is passed through the body of a man or animal.

We have already pointed out the violent shock which results from the discharge of a Leyden jar.

This shock is principally felt in the joints of the arms and wrist, knees and feet. When many people join hands together, there is no appreciable difference in the force of the shock experienced by one or another; it is as much felt by those in the middle as by those who, placed at the ends, touch the coatings of the jar. Nevertheless, it is no longer so when the number of persons is considerable, for then some of the discharge leaks across the circuit of persons through the ground.

With one Leyden jar, small animals and birds are easily killed. But the sensibility to shock does not depend only on the size of the body, or the size of the animal; cold-blooded animals, such as reptiles and frogs, resist much stronger discharges than those of hot blood.

Singer gives interesting details on the impression received on different parts of the body traversed by the discharge. The discharge, he says, "appears to act very powerfully on the nerves, and

when a shock traverses any part of the body following the course of a nerve it generally causes a grave accident. When the discharge of a battery passes through the head of a bird, the optic nerves are always injured or destroyed, and in repeating this experiment on a large animal they say the result is a general prostration of strength accompanied by trembling. Once, by accident I received through the head the charge of a strong battery: the sensation I felt was a violent and universal shock, followed by a momentary loss of memory and trouble in seeing; but these were only transient."

According to Morgan, if the diaphragm is placed in the path of a strong discharge from a jar having at least two square feet of coated surface, the lungs make a violent effort, followed by a shrill cry; but when the charge is small it never fails to produce a great desire to laugh. People whose temper and gravity are not touched even by the amusing circumstances, can rarely resist the *comic* power of electricity. A strong discharge produces on the diaphragm an effect which is frequently followed by sighs, involuntary tears, and sometimes even by fainting. If the shock follows the spinal column, it causes great feebleness of the lower members, so much that if a person is standing he falls sometimes on his knees, and often is thrown right down.

As electric shocks may cause accidents, more or less serious, especially if inconsiderate use is made of them, much precaution is necessary in this kind of experiments, even when it is only for amusement that they are repeated. It appears, nevertheless, that no disastrous result is to be feared when it is through the arm that the shock is directed.

Batteries with a large surface are dangerous for man and for large animals. It is said that the battery of Musée Teyler, at Haärlem, is powerful enough to kill an ox. "The energy of the shock excited in a living being," says Mascart, "increases with the difference of potential of the two conductors put into connection, and above all with the quantity of electricity discharged." Thus sparks of 20 or 30 centimetres' length furnished by an ordinary plate machine, or even by an induction coil, may be received with impunity, whilst the discharge of a battery of large surface, even if charged to so low a potential as to be capable of giving only sparks of 1 or 2 millimetres, may be terrible. So also, the electric quantity being equal, the

discharge of a series of jars "in cascade" gives a more violent shock than that of one bottle only. The result, then, from these general indications seems to be that the physiological shock varies with the electric energy of the discharge; that is to say, is proportional to the product of quantity and potential.

Another circumstance, however, plays an important *rôle*, that is the duration of the phenomenon; the shock is very feeble when the battery is discharged with the intervention of a moistened cord; it may be borne if you touch with very dry hands the two terminals of the same battery, and it becomes much more energetic if care is taken to moisten the hands to make them better conductors.

The physiological influence of electricity if it be applied under the form of disruptive discharges with production of isolated or successive sparks, or employed under the form of continued currents, would demand long development, which would be out of place here. In treating of apparatus for medical electricity, we shall come back to this subject. Since the time of the Abbé Nollet many able men have been occupied with this question, which demands a deep knowledge of physics, as well as a special acquaintance with biology; amongst the foremost we may name Matteucci, Du Bois Raymond, and a number of living authorities.

CHAPTER VI.

THE BATTERY.

§ 1.—*Galvani's Experiments.—Volta's Discoveries.*

IN every experiment that we have hitherto described, the only source of electrification developed on the surface of the body has been direct mechanical friction, or else indirect influence from a body which had been rubbed. This was the only source known at the end of the last century, when a happy chance suddenly revealed to physicists a new method of producing the mysterious agent, and caused a series of discoveries of the greatest interest both in a purely scientific point of view and in the value of their practical applications. Two great names belong to the origin of the movement which caused so much progress to the science of electricity; they are those of Galvani and Volta.

Galvani, an eminent doctor and professor of anatomy at the University of Bologna, was, one evening in the year 1780, busy in his laboratory with some friends making experiments relating to a nervous fluid in animals. On a table, where there was an electric machine used for the experiments, there had been placed by chance some recently-skinned frogs intended to make broth of; "One of Galvani's assistants casually put the point of his instrument near the internal crural nerves of one of the animals; immediately all the muscles of the limbs seemed to be agitated with strong convulsions. Galvani's wife was present, she was struck with the novelty of the phenomenon: she thought she saw that it occurred just at the moment when a spark was taken from the electric machine" (P. Sue; *Histoire du Galvanisme*). She warned her husband, who hastened to verify this curious fact, and he recognised

that the muscular contractions of the frog took place, in fact, every time that a spark appeared, but ceased while the machine was at rest.

This observation was the beginning of many experiments with the doctor by which he tried to prove the identity of the nervous fluid of animals with the supposed electric fluid. In 1786 he again continued researches of this kind. Being anxious one day to see

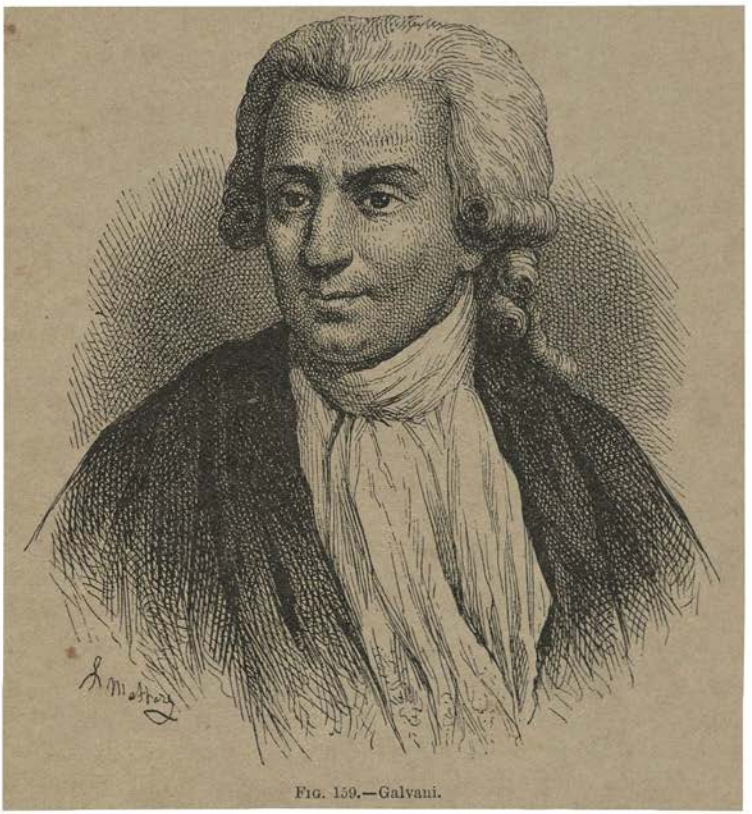

FIG. 159.—Galvani.

whether the influence of atmospheric electricity on the muscles of frogs would be the same as that produced in machines, he had for that purpose hung up a number of skinned frogs' legs on the balcony of a terrace of his house. He hooked the hind legs to the iron of the balcony by a copper wire which passed under the lumbar nerves. Galvani remarked with surprise that every time that the feet touched the balcony the frogs' limbs were contracted with quick convulsions,

though at that moment there were no signs of a stormy cloud, and, therefore, no particular electric influence of the atmosphere.

These facts suggested to Galvani the idea that there existed an electricity belonging to animals, inherent in their organisation; that this electricity secreted by the brain, resides specially in the nerves, by which it is communicated to the entire body; "that the principal reservoirs of this electricity are the muscles, each fibre of which may be considered as having two surfaces, and possessing by that means the two electricities, positive and negative, each of them representing besides, so to speak, a small Leyden jar, of which the nerves are the conductors."

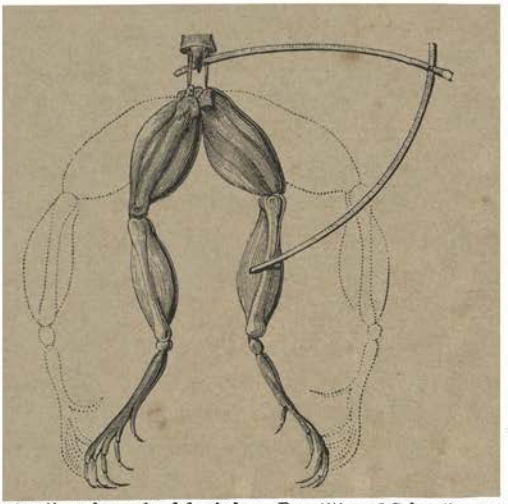

FIG. 160.—Contraction of muscle of frog's leg. Repetition of Galvani's experiment.

Hence the comparisons he makes between the muscular contractions in frogs and other animals, and the commotions produced by the discharge of a Leyden jar.

Alexander Volta, then Professor of Natural Philosophy at Pavia, repeated Galvani's experiments, but he very soon modified his explanations. According to Volta, the electricity developed was of the same nature as that which an electric apparatus produces. It is the contact between dissimilar metals which gives place to the production of electricity, one of the metals being charged with a positive, the other with a negative electrification; these charges combine in traversing the middle conductor of muscles and nerves. Then arose

between the two celebrated philosophers a discussion, a struggle, honourable to both, and, above all, profitable to science, which thereby became enriched by a multitude of new facts.

The invention of the marvellous apparatus which received the name of the *Voltaic pile* at last caused the theory of the Professor of Pavia to prevail, though Galvani's hypothesis on the existence of a sort of animal electricity is now recognised as partly true. On the other hand, Volta's ideas have been somewhat modified. This is not the place to relate the history of the struggle which we have just mentioned, nor to recount the researches of every kind which accompanied, and followed it; we must limit ourselves to describing the principal phenomena which belong to this branch of electricity, and to setting forth the explanations now given of them.

We have just seen that Volta thought that contact between the two metals was sufficient to produce electricity. In order to study the circumstances of this production, he designed an electroscope more sensible than the gold-leaf electroscope; it is the one we have described in the preceding chapter (Fig. 153, p. 254). Taking this apparatus and holding a metal bar formed of two pieces of copper and zinc soldered together, he put the copper in contact with one of the plates of the condenser, whilst the other plate is in communication with the ground through the finger. As soon as the communications were broken and the upper plate lifted, the gold leaves diverged; and he found that the lower plate was charged with a negative charge. Volta concluded from this experiment that the simple contact of the two metals had sufficed to develop on the copper a negative charge the presence of which was detected by the electroscope, and on the zinc a positive charge which flowed into the ground by the body of the observer. What confirmed this idea to him was, that after many attempts, at first fruitless, he succeeded in confirming the presence of the positive charge in zinc, by touching the plate of the apparatus with this metal. To obtain this result it was found necessary to place between the zinc and the copper of the plate a piece of cloth dipped in acidulated water.

In all this, Volta did not consider the possible effect of contact between the fingers, always more or less damp, on the zinc (a very oxidizable metal), nor, in the second experiment, the influence of the acidulated water on the same metal. Neither did it occur to him

that the surrounding air or films of condensed moisture on the surface of the metals *might* have an important part in producing the effect. However that may be, he admits that the contact of the two different metals, and generally of two heterogeneous bodies, gives place to the development of a force which was at one time called electric tension, but which is now by all electricians called *electromotive force*, because it is that force which moves or tends to move electricity, and to cause it to flow from one part of the apparatus to another.

Though Volta's theoretical views are now known to be inexact, or at least incomplete, the fact which it was their object to explain was real; and this fact suggested to the illustrious experimenter the con-

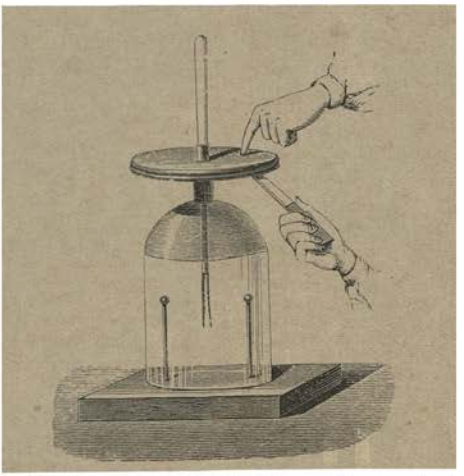

FIG. 161.—Volta's condensing electroscope. Electrification resulting at contact of dissimilar metals.

struction of an apparatus, which has justly been considered as one of the two greatest discoveries of physical sciences in modern times. We mean the pile which bears his name, *Volta's pile*, first made in 1800.

This simple and wonderful apparatus is constructed as follows:

Two disks, one of copper, the other zinc, placed one upon the other, form what we may call an *electromotive couple* or pair. A certain number of these pairs are placed one above another, separated as hereafter described, so that the two metals are always placed in the same order, the copper (c) at the bottom, the zinc (z) at the top, we will suppose. Each pair is separated from those adjacent to it by

means of a piece (*d*) of cloth, flannel, or paper, dipped in water acidulated with the addition of some drops of sulphuric acid. All these couples, forming a cylindrical *column* or *pile* (Figs. 162 and 163), are supported between three glass pillars, and rest on a wooden stand. Such is the pile as Volta constructed it, and which since has undergone many modifications which we shall afterwards consider. For the present we will describe its properties.

From one end to the other of the cylindrical column, each pair is charged with a feeble charge of electricity, positive on the zinc, and

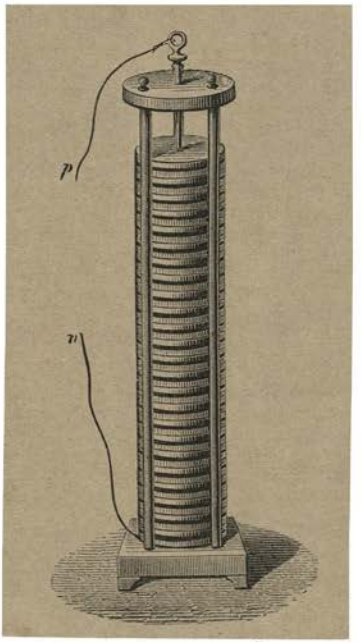

FIG. 162.—Volta's pile.

negative on the copper; it is easy enough to prove this by means of the condensing electroscope. But the potential of the charges varies according to the distance of each couple from the two extremities of the pile. If the potential of the middle pair is taken as a zero of reckoning, then, starting from thence, the potential increases positively up to the topmost pair, and increases equally negatively to the lowest pair. The greater the number of elements or pairs, the greater will be the difference of potentials between the two extremities of the pile. Instead of reckoning the middle point as zero we may take

any other. For example, we may count the bottom of the pile as zero, and we shall then have the electric *difference of potential*, as reckoned from the bottom upwards to any point in the series, increasing regularly all the way up to the top. When a pile like this (or indeed any kind of pile or cell) is not connected in circuit, no electricity flows through it, though the tendency to cause flow of electricity exists. To get an actual flow or current we must have a circuit or path (such as a wire) from one end of the pile to the other. When the pile is not connected in circuit the difference of potential between its two ends is an exact measure of its electromotive force.

In the pile constructed by Volta, and arranged as we have just said, it is a disk of copper which forms the lower extremity, whilst

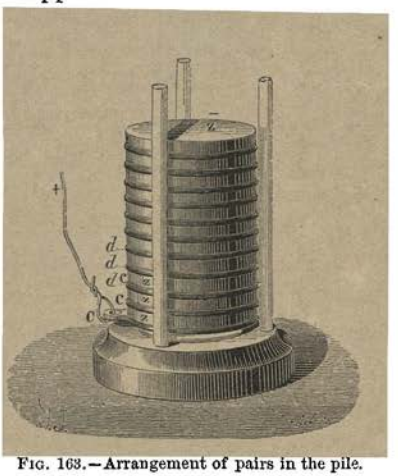

FIG. 163.—Arrangement of pairs in the pile.

the upper one is terminated by a disk of zinc. These two disks are omitted in the pillar piles as they are now constructed. The following is the reason. Volta believed that the true source of force in the electromotive couple was the contact between the two metals, zinc and copper; and that the piece of moist cloth was simply a conductor. But it is certain that the true seat of the working electromotive force is not between the copper and the zinc, but is at the surface of the zinc where it touches the moistened cloth. For every voltaic cell or voltaic pair may be looked upon as a sort of little chemical furnace where zinc is consumed as a fuel, it being chemically acted upon by the acidulated liquid and dissolved into it, just as the coal in a furnace

is chemically acted upon by and dissolved into the oxygen of the air. Moreover, the consumption of the zinc, the fuel, is proportional to the amount of electricity furnished by the pile. Hence it is only reasonable to suppose that as in the furnace the surface of the burning fuel is the seat whence the heat flows, so in the voltaic cell and voltaic pile the surface of the zinc is the seat of the electromotive force. Since, then, the copper disk at the lower end, and the zinc disk at the upper end, are useless, they may be omitted. But after these are removed, the electrical potentials remain distributed as they were before, that is, the potential is negative on the lowest zinc, positive on the uppermost copper. Hence the names *negative pole* and *positive pole* given to the two ends of the pile. In other words, the lowest zinc tends to dissolve into the acid liquid in the cloth laid upon it, and in so doing tends to drive electricity through the liquid into the copper disk above it; and this disk is therefore "at a higher potential." But this copper disk touches against the second zinc disk, which also tends to drive electricity upwards towards the second copper disk. It follows that the total tendency of these two pairs, acting together, is a doubly-great tendency to drive electricity upwards. Hence, if there are (as in the pile shown in Fig. 162) twenty-four sets of disks, the total tendency of the pile to drive electricity forward from one end to the other is twenty-four times as great as the tendency exerted by one single "pair." That is to say, the total electromotive force from bottom to top is twenty-four times as great as the electromotive force of any one "pair" reckoned from one zinc, through the moist cloth, to the copper next above it.

From the foregoing considerations it will be seen then that the true "element" or "pair" in a voltaic combination is *not* a pair of metal disks touching one another, but is a pair of metal disks (zinc and copper) separated by a liquid conductor which is capable of uniting chemically with one of the two metals (usually the zinc).

If the pile were arranged the other way up, that is with the zinc disks each above the moist cloth and the coppers below, then the electromotive force would tend to drive electricity down the pile instead of up it: the end zinc (at the top) would still be called the negative pole, and the end copper (at the bottom) would still be called the positive pole.

The pile thus constructed is ready for work. If you put its two

poles into communication by a conducting body, there ensues a rush of electricity through the conducting body, from the positive pole to the negative pole. For example, if you touch the positive pole with one hand, the negative pole with the other, you experience a shock like that which a small Leyden jar gives;[1] but with this difference, that as long as you continue to keep your hands in contact you continue to feel the peculiar sensations of heat and commotion in the nerves.

If the two poles are joined by two metal wires soldered, one to the copper, the other to the zinc, a current of electricity is found to flow continuously through the wire from the copper to the zinc, and the wire will, if thin, be warmed by the flow. You can notice, moreover, whenever you part the wires, a small but brilliant spark where the circuit is broken.

It is this property of the pile to furnish a continuous flow of electricity, that characterises this most important piece of apparatus, and gives rise to the varied effects which we shall describe later on.

§ 2.—*Various forms of Voltaic battery.*

Volta's pile has received very different forms, in order to render the use of it more convenient, and above all to increase the power. In the primitive vertical pile or column, this power was diminished by the running out of the liquid which the weight of the disks caused

[1] The sensation felt from these experiments with the pile, says P. Sue in his *History of Galvanism*, resembles the effect of a feeble charge in a very large Leyden jar battery. Its action is so slight that its influence cannot readily traverse dry skin. It is necessary then to moisten each hand, then, with a piece of metal held in each, to touch the top and bottom of the pile, or the conductors that communicate with its two ends. Or you can put the two conductors in two separate vessels of water, in which you plunge a finger of each hand. The greater the number of pieces in contact, the stronger is the shock. Twenty give a shock which is felt in the arms, when you take the proper precautions. With a hundred it is felt in the shoulders. The current of electricity acts on the animal system during all the time that it continues to make parts of the circuit; and if you have the least cut or scratch in the limbs in contact with the pile, you experience, at the place of the scratch, such a painful sensation that it is hardly bearable.

to leak over the outside; moreover there was so little liquid between the disks that it soon became exhausted of its acid, or dried up on exposure to the surrounding air. Besides, this pile took long to build up, and was not convenient to handle. The necessity of modifying its arrangement was soon recognised, and various combinations were imagined; but for all that we shall describe the principle is essentially the same as in the original pile. Volta himself suggested the modification known as the *cell*, in which the acidulated water is contained in a cup or cell into which dip side by side a piece of zinc and a piece of copper. When a set of such cells are joined in series, the copper of one to the zinc of the next, and so forth (exactly as in pile), the arrangement is termed a "battery of cells" or, simply, a *battery*.

The trough battery (Fig. 164), invented by Cruikshank, is formed of plates of zinc and copper soldered together arranged parallel in a

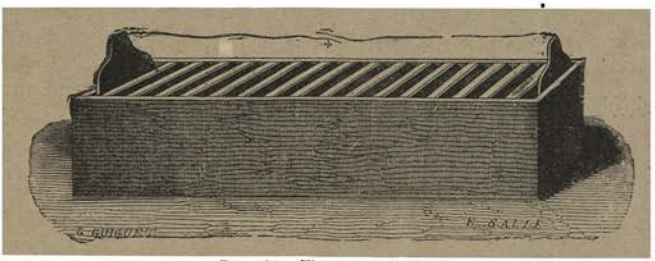

FIG. 164.—The trough battery.

case, or trough of wood lined with resin or pitch, constituting compartments or cells filled with acidulated water. When the battery is wanted for use the two metal wires which come from the two end plates must be brought together, the end copper forming always the positive pole, or the positive electrode, the zinc at the other end the negative electrode. By this arrangement the chief inconvenience of the vertical pile is done away with. Volta, after having invented the pillar pile, designed the crown of cups, of which Fig. 165 shows the arrangement. A slip of copper is joined, by soldering, to a slip of zinc, and the pair is then bent into a sort of arch, each extremity of which dips into the liquid of two consecutive cups or glasses, so that in each glass there is at the same time a plate of copper and of zinc. Two wires, one joined to the first zinc, the other to the last copper, in the series of cells, will serve to convey the current to any place where it has to be used.

Wollaston designed the following modification: each rectangular plate of copper is bent so as to envelop on both sides the zinc plate,

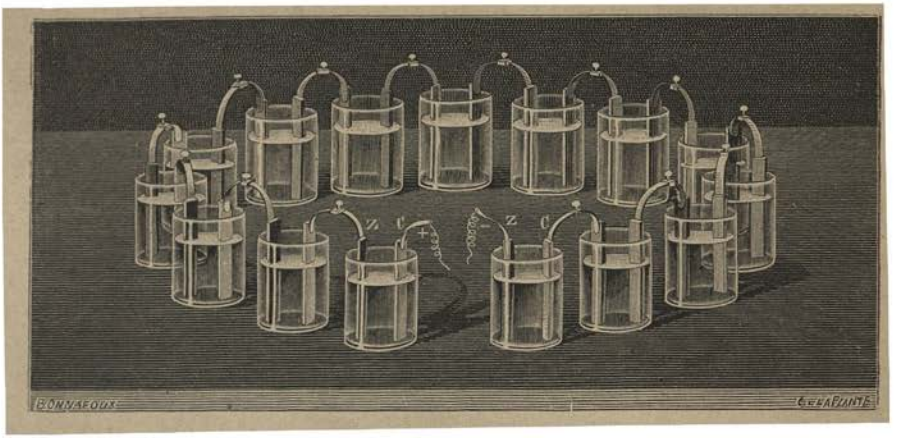

FIG. 165.—Volta's crown of cups.

from which it is separated at the top and bottom by pieces of wood (Fig. 166); a piece of copper carrying a suitable binding-screw or "terminal," is clamped to the upper part of the zinc. When it is

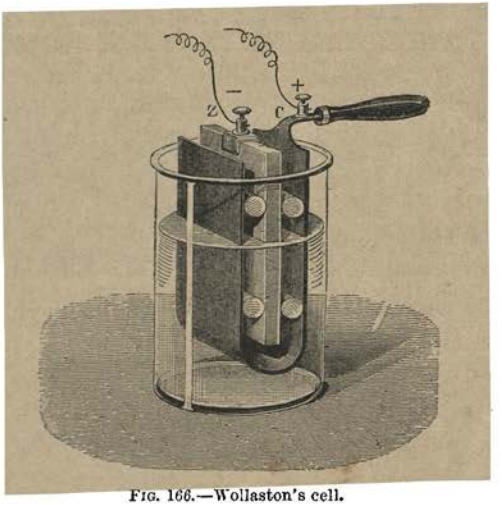

FIG. 166.—Wollaston's cell.

desired to connect up a battery of such cells, a copper strip is soldered to the top of each zinc plate and is bent over to join the copper of

the next cell. At last all the strips together are fixed to a piece of wood put across so that you may lower all the plates into the cells at once, or withdraw them from the liquid.

Jars of acidulated water are arranged under each pair of plates; when the cross bar holding the metal plates is covered the battery is put into action (Fig. 167). The advantages of Wollaston's battery, are, besides facility of using, the great extent of surface of metals which is in contact with the acid, and the small thickness of the layers of liquid which the electric current has to traverse in passing from the zinc to the copper plate in each cell.

Muncke's battery offers the same advantages as that of Wollaston; but it occupies less space, as it does not need a separate jar for each

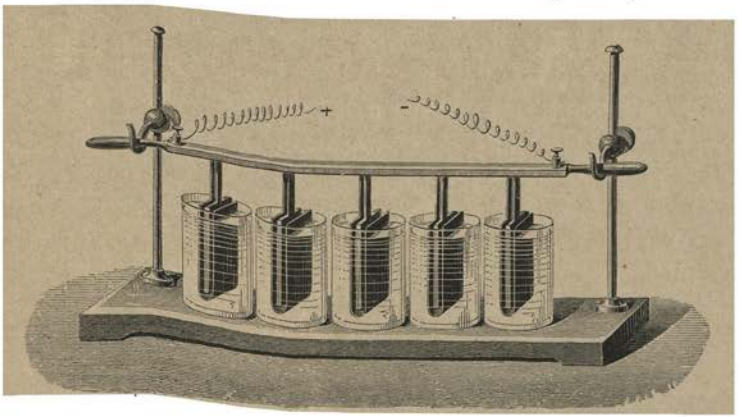

FIG. 167.—Wollaston battery.

cell. It is made of a series of thin plates of zinc and copper, bent like a U and enveloping each other, as Fig. 168 shows, which represents a horizontal section of plates. The whole is kept together by a wooden frame top and bottom, which is plunged into a trough containing acidulated water, when the battery is needed for use. In this form of battery there are however wasteful local electric currents flowing round in the liquid between the separate pairs.

Instead of multiplying the cells or elements of the battery, it is found convenient sometimes to increase their surface: a strong current conveying a great quantity of electricity, but with a feeble electromotive force, is then obtained. The coiled cell invented by Dr. Hare, of Philadelphia, fulfils this end. It is formed of two long

wide bands of copper and zinc, which are rolled together in a spiral round a wooden cylinder; but the two consecutive layers of the two metals are always kept apart by wooden rods, or pieces of cloth. The whole is plunged into a pail of acidulated water when the battery is

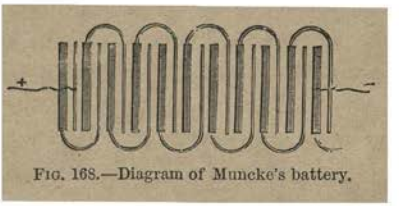

FIG. 168.—Diagram of Muncke's battery.

used (Fig. 169). Pouillet constructed, for the Faculté des Sciences of Paris, coiled cells on Hare's pattern, each plate of which had some five or six square mètres of surface. "One of these cells," he says, "is capable of producing very energetic physical effects, and when only twenty of these cells are united, you have a battery of extraordinary power to heat and liquefy instantly, not wires only, but rods of metal. Hare had made a battery so powerful that he christened it the "Deflagrator."

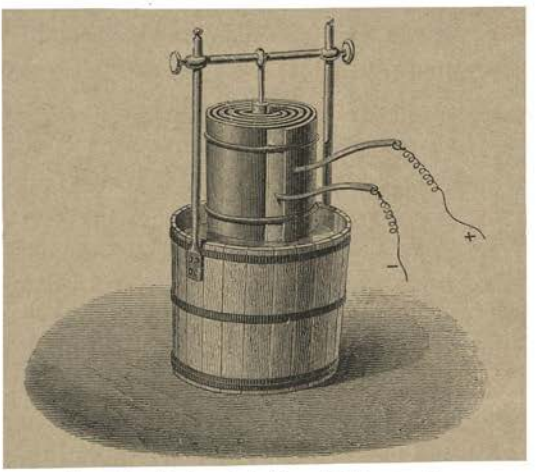

FIG. 169.—Hare's spiral cell, or "deflagrator."

The cells that we have just described, or others offering similar arrangements, have been long known and employed in scientific researches. A great number of new ones have since been brought into use, and we will describe only those most used. But before that

we will quote from Pouillet some details about the earlier ones, and their effects. In 1806, the Royal Institution of London became possessed of a battery of 2,000 elements on the trough system; each element having a surface of 100 or 120 square inches. It was with this apparatus that Davy succeeded, two years later, in making the great and beautiful discovery of the decomposition of potash and soda. At the same time Gay-Lussac and Thénard constructed for the École Polytechnique a battery of 600 elements, each of nine square decimetres of surface; they used it for their numerous and important chemical works. "The most powerful ordinary electric machines," adds Pouillet, referring to the friction machines of glass and silk, "can do nothing at all approaching these powerful batteries. To establish, for an instant, communication between the poles with the hands, would suffice to kill as by a thunderbolt. Rods of platinum of five or six millimetres in diameter and more than a mètre in length, placed between the poles, are maintained in a state of clear incandescence and almost fusion, during all the time that they join the poles; other metals will become fused, or burn, according as they are more or less electric conductors, more or less fusible, and more or less oxidisable. In short, there are no chemical compounds which conduct which are not rapidly resolved into their elements as soon as they are placed between the poles of these batteries. Nevertheless it is rarely necessary to have recourse to apparatus of such power. Trough batteries of 100 elements, Wollaston's of twenty or thirty, or coiled piles of fifteen or twenty, are sufficient to give an idea of these different results. When the shocks become feeble, it is almost always necessary to have the hands moistened to feel them. The physical effects of fusion and combustion are easily rendered sensible on thin leaves of gold, silver, or tin, on fine platinum wire a few inches long, or on iron or steel wire of the same dimension, &c. Physical effects also are produced with less intensity."

§ 3.—*Cells which give constant currents.*

In all the cells that we have described, the currents, and the effects which they produce, diminish in intensity very rapidly. The reasons for this are easy to understand. On one hand, the zinc oxidises, partially decomposing the acidulated water, and taking its oxygen from it; the oxide thus formed combines with the sulphuric acid, and gives place to the formation of a certain quantity of sulphate of zinc. There is then, chiefly under the influence of this chemical action, an alteration of the liquid of the cell, and in consequence a slight diminution of its activity, and of the current which it produces. On the other hand, the hydrogen of the decomposed water comes to the surface of the copper plate; the bubbles which are deposed on this surface cover it soon with a continuous layer of gas, the very slight conductivity of which makes it an obstacle to the passage of the current. Moreover, and this is vastly more important, hydrogen is, like zinc, a fuel, and tends to unite on its own account with the oxygen of the liquid, and hence it tends to set up at this end of the cell an electromotive force in opposition to that of the zinc at the other end of the cell. This effect, which causes a rapid falling off in the current when once the copper plate has become covered with hydrogen bubbles, is termed "polarisation." A cell which has got into this state is said to be "polarised."

The study of these causes of weakening and the means of remedying them is due to Becquerel, who introduced in the year 1829 the employment of two different liquids separated by a porous partition, each of which enclosed one of the electrodes. It is on this principle that the first constant currents cells were invented, and which we will now describe.

Let us begin with Daniell's cell, so called from the accomplished professor who invented it in 1836.

One form of Daniell's cell is represented in Fig. 170. It consists of two jars, the outer one of glass or stoneware, the other placed inside of porous earthenware. Between the two jars acidulated water (that is, sulphuric acid with about six to ten times its own bulk of water) is poured, and inside the porous jar a saturated solution of sulphate of

copper. In the first liquid a large plate of amalgamated zinc is placed, of a cylindrical form, and in the other a copper cylinder. The actions that go on in the cell are as follows:—

The zinc begins to act as a fuel, decomposing the acidulated water and dissolving into it, forming sulphate of zinc in the solution, and liberating hydrogen atoms, which are driven, charged with electricity, toward the copper plate. These hydrogen atoms, traversing the inner porous jar, find themselves surrounded by the solution of sulphate of copper. Now hydrogen is a better fuel than copper, having a greater tendency to combine with oxygen and with sulphuric acid than

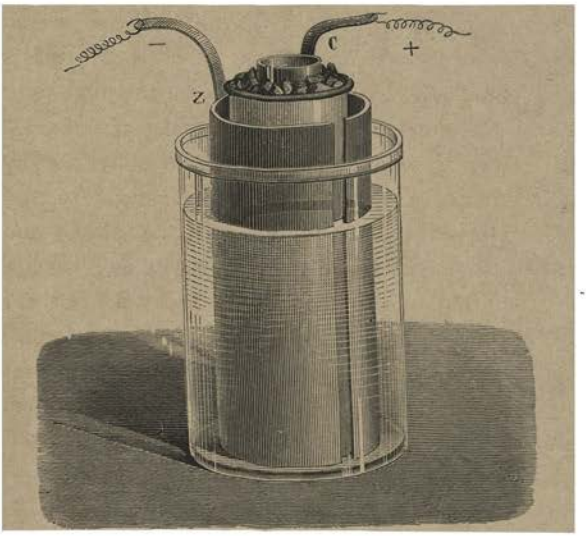

FIG. 170.—Daniell's cell.

copper. Hence the hydrogen atoms decompose the copper sulphate and drive out the copper atoms, giving up to them the electricity with which they were charged. The copper atoms are thus driven charged with electricity to the copper plate, which therefore becomes positively electrified and at the same time receives a coating of metallic copper as the atoms settle upon its surface. The copper itself has a certain tendency to act as a fuel, to dissolve into the surrounding liquid, and to set up a counter electromotive force of its own; but its electromotive force is less than that of the zinc at the other end of the cell, and is constant, as the surface is always bright copper.

The nett electromotive force of Daniell's cell is then the difference between these two opposite electromotive forces. The resulting current may not be a very strong one, but it remains practically constant if care is taken to keep up a supply of crystals of sulphate of copper inside the porous cell. The zinc and copper preserve their surfaces intact, but whilst the zinc diminishes in thickness the copper on the contrary increases. To put the matter in exact numbers, the tendency of zinc to dissolve and drive electricity in sulphuric acid is measured as about 1·85 *volts* of electromotive force, while the tendency

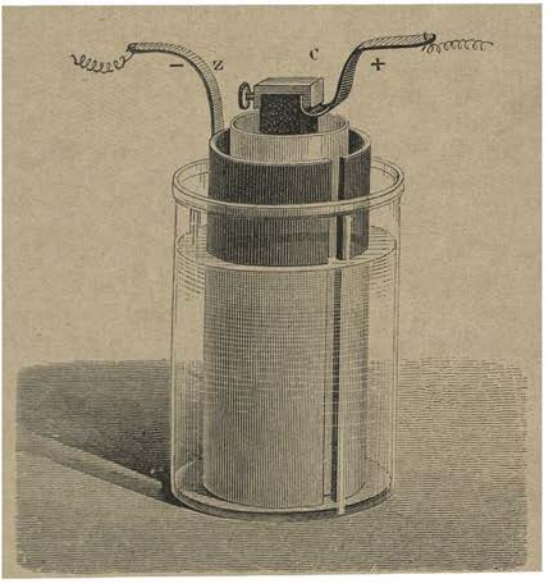

FIG. 171.—Bunsen's cell.

of the copper is only about 0·8 *volt*. Hence the electromotive force of the Daniell's cell is about 1·05 or a little more than *one volt*. This number is useful for comparison with other cells. It varies a little with the strength of the solutions.

Bunsen's cell (Fig. 171) is arranged like Daniell's, only the copper cylinder is replaced by a cylinder of hard carbon, and the solution of sulphate of copper by strong nitric acid. Bunsen's cell is preferable to Daniell's as regards the energy of the current, but inferior in its continuance. Its electromotive force is about 1·9 or nearly two volts; and the internal resistance offered by the layers of

liquid is less, for nitric acid is a good conductor. Sometimes the form pointed out in Fig. 172 is given to it, which offers the advantage of electrodes of greater size for a less volume of liquid. The zinc is in this case bent in a U-form.

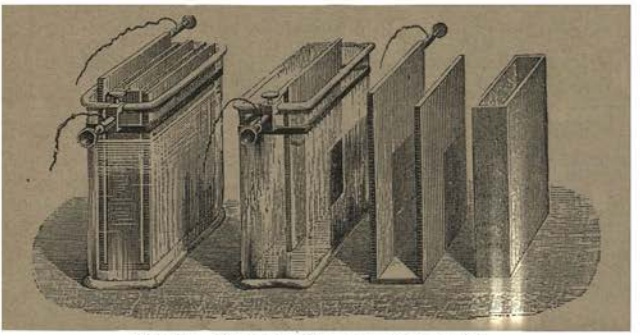

FIG. 172.—Bunsen's cell; rectangular pattern.

By uniting many cells together in series, the positive pole of one cell to the negative of the next, batteries are formed. Their electromotive force is proportional to the number of cells thus united. Fig. 173 shows five Bunsen's cells so united. The zinc of the first

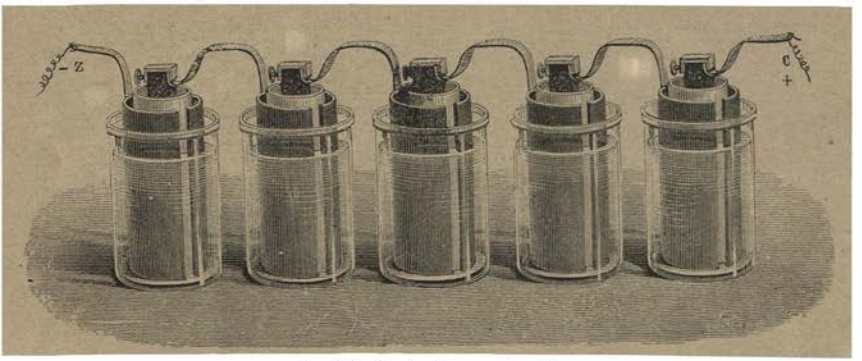

FIG. 173.—Series of Bunsen's cells.

cell is the negative pole, and the carbon of the last cell the positive pole of the battery.

Bunsen's cell had been preceded by Grove's, which differed from it in that, instead of carbon or copper, there was a plate of platinum. This metal, though dearer, is cleaner to handle; hence it is preferred in England. Grove also anticipated Bunsen in suggesting the use of

the cheaper carbon kathodes. For applications demanding much power Bunsen's cells are very much used, but they offer one great inconvenience, that of giving off fumes (nitric oxide) which are both highly corrosive and poisonous, so that they can scarcely be used except where the air can be easily renewed. Daniell's cell, though less powerful, has not this inconvenience; it has besides a constancy which renders it invaluable when there is need of steady currents. It is of great use in electric telegraphy.

Some years ago a modification of Daniell's cell was made by Sir William Thomson of Glasgow. Here are the terms in which Professor Clerk Maxwell describes this modification, represented in

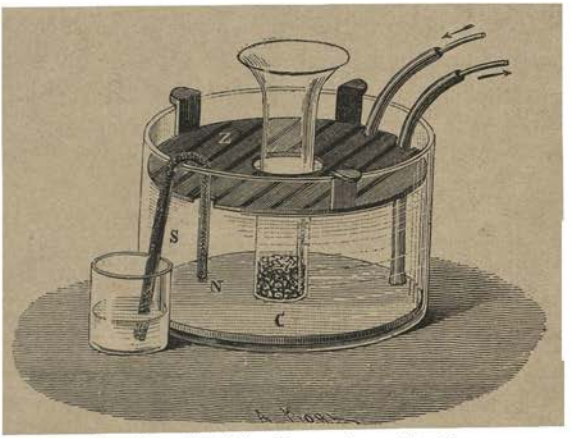

FIG. 174.—Sir William Thomson's gravity cell.

Fig. 174: "In all forms of Daniell's battery, the final result is that the sulphate of copper finds its way to the zinc and spoils the battery. To retard this result indefinitely, Sir W. Thomson has constructed Daniell's battery in the following form:—In each cell the copper plate is placed horizontally at the bottom, and a saturated solution of sulphate of zinc is poured over it. The zinc is in the form of a grating and is placed horizontally near the surface of the solution. A glass tube is placed vertically in the solution with its lower end just above the surface of the copper plate. Crystals of sulphate of copper are dropped down this tube, and, dissolving in the liquid, form a solution of greater density than that of sulphate of zinc alone, so that it cannot get to the zinc except by diffusion. To retard this

process of diffusion, a siphon, consisting of a glass tube stuffed with a cotton wick, is placed with one extremity midway between the zinc and copper, and the other end in a vessel outside the cell, so that the liquid is very slowly drawn off near the middle of its depth. To supply its place water or a weak solution of sulphate of zinc is added above when required. In this way the greater part of the sulphate of copper rising through the liquid by diffusion is drawn off by the siphon before it reaches the zinc, and the zinc is surrounded by a liquid nearly free from sulphate of copper, and having a very slow downward motion in the cell, which still further retards the upward motion of the sulphate of copper. During the action of the battery copper is deposited on the copper plate, and the sulphuric acid travels slowly through the liquid to the zinc, with which it combines, forming sulphate of zinc. Thus the liquid at the bottom becomes less dense by the deposition of the copper, and the liquid

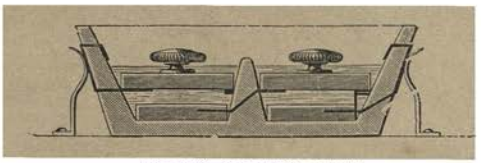

FIG. 175.—Marié-Davy's cell.

at the top becomes more dense by the addition of the zinc. To prevent this action from changing the order of density of the strata, and so producing instability and visible currents in the vessel, care must be taken to keep the tube well supplied with crystals of sulphate of copper, and to feed the cell above with a solution of sulphate of zinc sufficiently dilute to be lighter than any other stratum of the liquid in the cell." The cell we have just described is what is called a "gravity battery." The reason for this name is obvious.

We will now describe some cells which will be mentioned afterwards in the chapters on the various applications relating to electric telegraphy, namely the Marié-Davy, Callaud, and Leclanché cells.

A glass jar (Fig. 175) of wide open form, and divided into two compartments, forms a double cell of Marié-Davy's battery. On the bottom is a carbon plate covered with a paste of sulphate of mercury; above is a plate of zinc furnished with a handle, and

resting on metal supports fixed to the sides. The plates are covered with acidulated water, the carbon of one of the compartments is bound by a wire to the zinc in the adjacent compartment, and the whole forms a cell which is united with other similar cells to form a battery. This first arrangement has been modified, and the form of the Marié-Davy cell often resembles that of Daniell with a porous pot and separate liquids. It is very constant, but there is a very serious drawback; the sulphate of mercury is a very poisonous salt, and the employment of it dangerous.

"Gravity" cells of various kinds, beside those of Sir W. Thomson, have been greatly used in many countries. Varley in England, Minotto in Italy, Meidinger in Germany, and Callaud in France have all devised such cells.

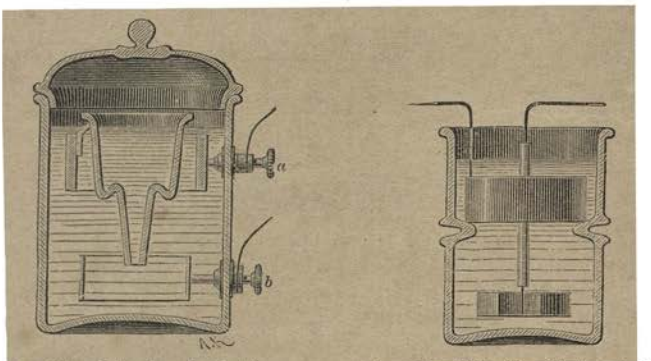

FIG. 176.—Callaud's cell; first form.

FIG. 177.—Callaud's cell; telegraph pattern.

Callaud's cell, of which Figs. 176, 177, 178, represent different types, is a "gravity" cell; we will give the author's own description of it:—

The object which the inventor proposed, he says, is the doing away with the porous pot of Daniell's cell. The modification of it has been tried with Daniell's cells; the difference of the density of the liquids is greater than with those of other cells.

The model which is the type of this cell is represented in Fig. 176. The outer jar is of the size of telegraph cells; it is pierced at *a* and *b*; in each of these holes a support is placed, a sort of bolt ending in a screwed stem, to which is soldered the zinc at the top, copper at the bottom; a washer shield of indiarubber serves to make it

tight; a nut screwed outside keeps the whole in place; a binding-screw above the nut receives the conductors. A glass funnel, supported by the zinc, has its lower open extremity near to the level of the copper plate. Into the cell is poured some water, either pure or charged with a small quantity of sulphate of zinc, salt, or sulphuric acid, and into the funnel a solution of sulphate of copper; this very heavy solution falls to the bottom of the jar, and raises, without mixing with it, the upper liquid, which then reaches the zinc. The current immediately starts. Crystals of sulphate of copper are thrown into the glass funnel and maintain the solution saturated as fast as the working of the cell tends to weaken it.

In the model of Fig. 177, the zinc is supported by a ledge which is made inside the glass vase near the middle of its height. The

FIG. 178.—Gravity cell: American pattern.

copper plate at the bottom is rolled in a spiral, as in the American type of gravity cell (Fig. 178), and the zinc has the form of a wheel, with four spokes supported by a stem in the middle. The rolling the plates in a spiral has for its object to increase the surface of the electrodes. Sometimes a piece of lead is used instead. It rapidly becomes coated with copper. The Meidinger cell, which is represented in Fig. 179, is another form of gravity cell: the section we give of it renders description superfluous.

The bichromate of potash cell (Fig. 180) is convenient for use in a course of lectures or in a laboratory. It is a cell with only one liquid, thus arranged: Two plates of hard, good-conducting carbon connected together form the kathode or positive electrode; they both dip into a saturated solution of bichromate of potash with some

sulphuric acid added, and they are fixed to the ebonite cap of the cell.

The anode is a plate of zinc half as long as the carbon plates,

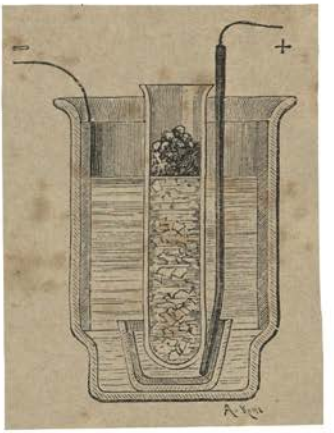

FIG. 179.—Meidinger's cell.

and is mounted on a stem that can be pushed down between the two positive plates. It forms in the liquid sulphate of zinc, whilst the

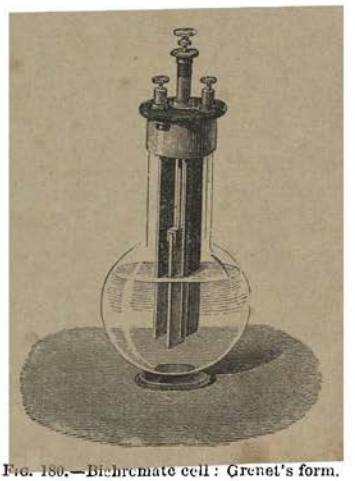

FIG. 180.—Bichromate cell: Grenet's form.

bichromate of potash is turned to chrome alum, and the hydrogen, which would otherwise be disengaged, is oxidised to form water. The deposit of hydrogen round the carbon plates is thus chemically

prevented. When the cell is not in use, the central stem is raised and the zinc is thus drawn out of the liquid. Of the two terminals, one is attached to the carbon plates, and forms the positive pole; the other to the central stem and to the zinc, and forms the negative pole of the cell. The employment of bichromate of potash is due to Poggendorff. The convenient bottle-form is due to Grenet. In recent years, bichromate of soda and chromic acid have been advantageously used instead of bichromate of potash in these cells. A bichromate cell, having the zinc in an inner porous cell filled with dilute acid, has been extensively used in telegraphy.

The Leclanché cell is formed of an outside jar of glass enclosing a solution of sal ammoniac. An inner porous pot is filled with a

FIG. 181.—Leclanché's cell: porous pot form.

mixture of equal parts of fragments of peroxide of manganese and retort carbon, broken into large granules. It is this mixture which constitutes the depolarizing agent of the cell. A stick of zinc dips, through the narrow entrance of the exterior jar, into the solution of ammonium chloride and forms the negative electrode. When the circuit of the cell is completed, the zinc begins to dissolve and decomposes the solution, forming chloride of zinc, the hydrogen being carried through the porous pot towards the carbon, where it meets the peroxide of manganese, and is slowly absorbed by it, reducing it to sesquioxide of manganese; water and gaseous ammonia being evolved at the same time.

In the model shown in Fig. 182, the porous pot is suppressed;

the mixture of peroxide of manganese and carbon, having been submitted to considerable pressure while gently heated, has become a solid agglomerate, which can readily be attached to the plate of carbon. The stick of zinc, separated by a piece of wood from the positive electrode, is held on to it by bands of indiarubber. In one or other of these very simple forms, Leclanché's cell has rendered great service

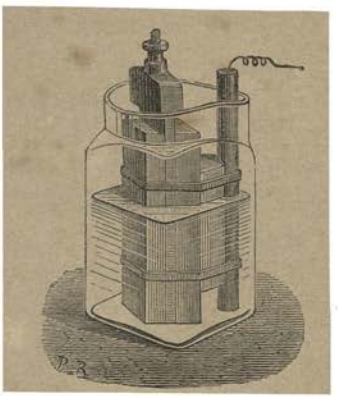

FIG. 182.—Leclanché's cell: agglomerate form.

in the industries; more particularly for electric bells and telephones where occasional currents only are required for a short time. Its constancy is such that it can work without attention for months; and the same cell may serve during years of continued use. It must not however be used for more than a few minutes at a time.

§ 4.—*Physico-chemical Theory of Batteries.*

In the phenomena which we have passed in review up to the present, the sources of electricity, or the different modes of producing the electric agent, may be classed in four categories: friction, induction, contact, and chemical action. We have nothing to add to what we have already said of the two first methods. Electricity developed by friction appears like a transformation of mechanical power into electric power. In what does this latter consist? What is the kind of movement which animates the molecules of an electrified body, or the atmosphere of ether in which they are supposed to

be enveloped? Nobody knows; or rather, no one has as yet done more than suggest conjectures on these delicate questions. All that one knows is that there are these methods of developing electric effects. We have seen that they show themselves under different forms—attractions and repulsions, heat, light, chemical combinations and decompositions; that is to say, visible movements or molecular and atomic movements. What is known, and what must be admitted as a certain consequence of a mechanical principle now universally proclaimed, of the conservation of energy, is that there is an equivalent for the work spent to produce the electricity,—an equivalent which may be calculated by reckoning up and totalising each of the mechanical, chemical, or physical effects of which we have given an enumeration.

The development of electrification by the contact of heterogeneous bodies, which Volta showed to exist, seems now to be perfectly demonstrated.[1] Attempts have been made to explain this phenomenon by mechanical actions, such as the pressure of metals one against the other; or by chemical actions excited by the moisture of the hand, or the pieces of cloth of the pile, or by the action of layers of surrounding air. It is certain that in Volta's original experiments these various causes may have concurred to produce the electricity of which his condenser indicated the presence. But there has been much dispute as to the true origin of the "contact force," and as to the seat and origin of the electromotive forces in voltaic cells.

As for the electricity developed as the result of chemical actions, it is demonstrated by the working of numberless cells, the most

[1] "The incredulity of most of the philosophers who refuse to admit it," says Mascart, "arises mostly from the thought that this fact, if admitted, would as a consequence lead to the admission of something analogous to perpetual motion; but we have seen that Volta's law expresses nothing but the impossibility of producing electricity without work. When two heterogeneous plates are put into contact, for example, without doubt they attract by the fact alone that they are electrified in contrary directions or charged to different potentials; but to utilize these charges of electricity, it is necessary to separate the plates and to conquer entirely the attraction which they exercise on each other. It is the same with a steel needle that is put in contact with a magnet: the needle becomes magnetized, and the magnetic energy which it acquires is represented by the work that is necessary to detach it from the magnet. Contact of electricity is as powerless as magnets to produce any work whatever without an equivalent mechanical expenditure" (*Treatise on Statical Electricity*, tome ii. p. 531).

important of which we have already described. The following experiment shows how to produce by the chemical action of a voltaic cell a statical charge :—

Place a slip of copper in a glass which contains nitric acid diluted with water (Fig. 183). Join the slip to the lower plate of a condensing electroscope ; whilst the liquid, as well as the upper plate, communicates by a platinum wire to the earth. As soon as the two plates are separated, the gold leaves diverge, and it is found that the apparatus is charged with a negative charge of electricity. If the order of contact is changed, the acid united by a metal wire to the lower plate of the condenser, whilst the other plate and the copper communicate with the ground, the apparatus will be charged with a positive charge of electricity.

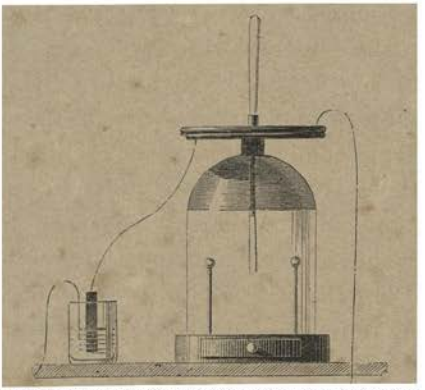

FIG. 183.—Electrification developed by chemical action.

A similar result—that is to say, a disengagement of electricity more or less energetic—may be obtained by exciting any chemical action between two bodies. Two solutions, one alkaline, the other acid ; or two salts, one acid and the other neutral or alkaline, when put in contact, give place to a production of electrification, which is positive on the body that represents acid, and negative on that which is the base.

The time is come for endeavouring to explain the relation between the electricity that is obtained from batteries and that obtained from the various electrical machines worked by the aid of friction or influence. Many writers distinguish by two different names these two sorts of electricity. They give the name of *static electricity* to

that which is developed on the surface of the conductors of electric machines, or on insulators like the resin cake of an electrophorus, or to that which is condensed at the coatings of a Leyden jar. They give the name of *dynamic electricity* to that which spreads along the wires or terminals of a battery when the circuit is completed between the negative and positive poles of the apparatus. [All that these terms really mean is that in the one case the electricity is standing still in the form of *charges* at the surface of things, and in the other case is running along in the conductors in the form of *currents*.]

When you work an electric machine—a plate machine for example—the electricity which is developed on the glass is transmitted by induction to the conductor, which therefore receives a charge. This charge goes on increasing as the machine is worked, up to a certain limit. Beyond this maximum charge, which depends on the size of the conductor and the power of the machine, any electricity which you might produce if you continued to turn the handle would be lost by leakage through the air or through its supports. If the conductor, instead of being insulated, were put in communication with the ground, the charge of electricity would pour down as fast as it was produced; and this flowing would constitute a current, like that of the battery, but probably a much weaker one. The charge gathered on a body by the aid of ordinary machines remains on the surface of the body if there is no leakage, and it is for this reason that the phenomena proceeding from these sources are called phenomena of *static electricity*.

[The same kind of thing is true also in a battery. Each cell may be looked upon as a sort of electric machine in which there is energy stored up in an electro-chemical way; and its presence is manifested by the tendency it possesses to drive a current of electricity along the wires that constitute the circuit. But suppose there is no complete circuit—let one of the wires proceeding, say, from the positive pole, be insulated at its end, electricity will be driven into that wire; but as there is no way out of it, the wire will remain charged positively. Or if to the end of the wire is hung a metal ball, not touching anything else, this ball will also become charged. But there will be no continuous current, because there is no circuit. And the charge will be a feeble one, probably incapable of manifesting a spark when touched; for it requires some thousands of volts to give

a spark through the air, whilst the battery will have only a few volts of electro-motive force: for example, a battery of ten Daniell's cells would have only about eleven volts.

There has been much controversy amongst electricians as to the true theory of the voltaic cell. Volta's theory was that the currents were originated by the mere contact of dissimilar metals. On the other hand De la Rive and Faraday maintained the view that the whole of the phenomena were due to the chemical action of the liquids upon the metals. According to the great principle of the conservation of energy, it is quite impossible for the continuous output of energy that is manifested in the circuit of a voltaic battery to occur without a corresponding expenditure of energy taking place at some part of the system. It is as impossible for mere contact of two substances to furnish this supply of energy as for perpetual motion to occur. Nevertheless, there can now be no question as to the reality of the fact that when a piece of zinc and a piece of copper are brought into contact with one another in the air, the zinc becomes positively and the copper negatively charged, or rather the air that is in the immediate neighbourhood of their surfaces becomes charged thus. If the two wires from a sensitive quadrant electrometer are brought, one near to a zinc plate, the other close to a copper plate, both surrounded by air, and not touching one another, there will be scarcely any appreciable difference of potential observed: but if now the two metals are made to touch, a difference of potential of about one volt in amount is observed in the electrometer. Before the metals touch the zinc itself is at about 1·85 volts lower than the surrounding oxidising medium, whilst the copper is itself at about 0·8 volts lower than the surrounding medium, having a less tendency to become oxidized. As soon as the two strips are made to touch one another there is a rush of electricity through the metallic contact from the copper to the zinc, so as to equalize the potentials of the metals themselves: and at the same instant the air outside the zinc takes as the value of its potential about 1·05 volts higher than that of the air outside the copper. At the same instant a small portion of the zinc surface is oxidized. It is important to notice in this connexion that the order in which the metals stand in the electromotive series in *air*, or in an oxidizing acid, is practically the same as the order in which they stand with respect to the amounts of heat

which they can respectively give out in combining with a given amount of oxygen. Their electromotive force (or tendency to drive electricity along the circuit), is a measure of the potential energy of their combination with the oxygen of the surrounding medium. Of late years the controversy has turned rather more directly upon the question of the seat of the electromotive force in the cell than upon its origin. Formerly the junction of the two metals was looked upon as the seat of the electromotive forces. But the real starting-point of the electromotive force in a voltaic cell is, according to modern ideas, at the surface of the zinc where the chemical action is setting free the potential energy, just as in a furnace the seat of the thermal forces is at the surface of the burning coal. According to this view, the cell being regarded as a sort of little electro-chemical furnace wherein zinc is consumed, the current starts from the surface of the zinc, penetrates through the liquid, passes up the copper or carbon kathode, and then starts on its outward journey through the circuit, and so back to the zinc.—ED.]

CHAPTER VII.

ELECTRO-CHEMISTRY.—THERMO-ELECTRIC CURRENTS.—SECONDARY CURRENTS.

§ 1.—*Electro-chemical Phenomena.—Electrolysis.*

WHEN the current of the battery traverses a chemical compound in a liquid state or in solution, it generally decomposes it into the two constituent parts, one of which appears on the side of the positive pole, and the other on the side of the negative, that is, at the two places where the current enters the liquid and where it leaves it. The chemical effects of electric currents have become of so much importance that their study forms a special branch of the science, to which is given the name of *Electro-chemistry.*

The first phenomenon of decomposition was that which Carlisle and Nicholson discovered in 1800, namely, the decomposition of water. Having passed the current of a voltaic pile, formed of discs of silver and zinc, through water, they noticed that at the end of the copper wire which came from the negative pole of the pile some gaseous bubbles were given off, which they ascertained to be hydrogen; the other wire became rapidly oxidised. On substituting for copper platinum, which is not attacked by oxygen, bubbles of this latter gas were given off in the same way from the positive wire. That is to say, when two platinum wires were used, oxygen gas was given off in bubbles from the surface of the wire by which the current entered the water, and hydrogen gas was at the same time given off in bubbles from the surface of the wire by which the current left the water.

Nowadays, to bring about this decomposition, an apparatus is

employed to which Faraday gave the name of *Voltameter*. It is shown in Fig. 184, which shows how the operation is carried out.

In the bottom of a conically formed glass vessel, two holes are pierced, through which are passed two platinum wires, and they are cemented in with sealing-wax. The two platinum wires are then united respectively to the two terminals of a battery, consisting in the drawing of two of Bunsen's cells. The vessel is then filled with water, to which a few drops of sulphuric acid have been added. Two graduated glass tubes full of water are inverted in the vessel so as to cover the platinums. As soon as the electric current passes, bubbles of gas are seen to be liberated round the platinums, and rise to the upper part of the glass tubes. One of these gases is hydrogen, the other oxygen.

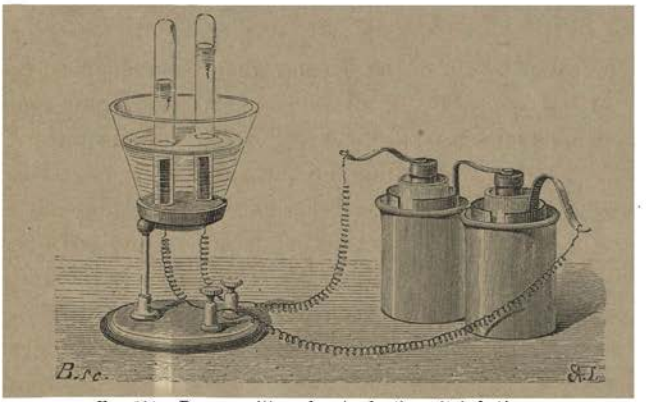

FIG. 184.—Decomposition of water by the voltaic battery.

It is easy to distinguish these two gases; a lighted match or splint of wood that has just been blown out, leaving a spark, will kindle again into a flame immediately on being placed in the tube of oxygen gas, which must be removed from the apparatus for the purpose.

The hydrogen can be recognised by allowing a little air to mix with it, and then applying a lighted match, when immediately there will be a small explosion, for hydrogen forms with air an explosive mixture.

The volume of the hydrogen gas is always double the volume of the oxygen, those being the proportions in which they exist together in water.

The operation in which, by the aid of the battery, we resolve a chemical compound into its constituent parts, is called *electrolysis;* and bodies capable of being electrolysed are themselves called *electrolytes.* The metal wires or metal plates where the decomposition takes place are called *electrodes.*

Faraday, to whom we owe these names, also gave the name of *anode* to the electrode by which the current enters (the one joined to the positive pole of the battery), and the name of *kathode* to the electrode by which the current leaves the decomposing cell. The kathode is the one connected to the negative pole, or zinc pole, of the battery. The products of the electrolytic decomposition are called *ions; kations* means those which come from the kathode, and *anions* those which proceed from the *anode.* Stated in precise terms, water is an electrolyte; its two ions are hydrogen and oxygen; hydrogen is the kathion, and oxygen the anion.

A few years after the discovery of the decomposition of water by the voltaic current, this new method of electric analysis furnished to the illustrious Davy the means of making many brilliant discoveries. Until then the alkalis, potash and soda, had been considered simple bodies. Lavoisier, who suspected that these alkalis were compounds, had been unable to effect their decomposition.

The English chemist succeeded in effecting this memorable decomposition, and discovered, in the same year 1807, the five following metals :—potassium, sodium, barium, strontium, and calcium.

He placed a small piece of potash on an insulated disk of platinum communicating with the negative pole of an electric battery of 250 cells (copper and zinc) in full activity. A platinum wire communicating with the positive pole was put in contact with the upper surface of the potash. The whole apparatus was worked in free air. In these circumstances a very energetic action took place; the potash melted at the two surfaces. There was on the upper surface (positive) a deal of effervescence, caused by the disengagement of gas; on the lower surface (negative) there was no gas, but there appeared little globules possessing a metallic lustre, quite like globules of mercury. Some of these globules, as they formed, burned with an explosion and a brilliant flame; others lost by degrees their brilliancy, and were covered finally with a white layer. These

globules formed the substance he was looking for; it was a peculiar combustible element, the base of potash, potassium.

Davy's memorable experiment may be repeated in the following manner. On a plate of platinum or carbon connected to the positive pole of a battery (Fig. 185) is placed a piece of caustic potash, the upper surface of which is hollowed out like a cup to receive a globule of mercury. The negative terminal of the battery dips into the mercury. The circuit being thus closed, electrolysis begins; gaseous bubbles of oxygen are disengaged on the platinum, and potassium is formed in the mercury and dissolves there, forming with the latter metal an amalgam, so keeping the metal from active contact with the air. Afterwards the mercury is separated from the amalgam by heating in a current of dry hydrogen gas, and the potassium is obtained in a state of purity.

The electrolysis of soda, baryta, and lime may be effected by the same process. Magnesia and alumina resist electrolytic decompo-

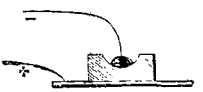

FIG. 185.—Decomposition of caustic alkalis by the battery.

sition: but if, instead of employing these bases, the chlorides of magnesium and aluminium in a state of fusion by heat are used, you obtain these same two metals, which are carried to the negative pole. The deposit of aluminium is, however, not in the form of a satisfactory metallic film.

In all these compound binary conductors which have been submitted to electrolytic action, it is always the metal which goes to the negative electrode or kathode, and the non-metal to the positive electrode or anode. It is the same with iodides, bromides, and chlorides when they are decomposed by the battery: the iodine, the bromine, or the chlorine go to the anode or positive pole, whilst the metal is deposited on the kathode.

The electrolysis of salts may give rise to more complex phenomena. If it is a question of a metallic salt in solution in water, for example a solution of sulphate of copper, the metal goes to the kathode or negative electrode; the oxygen of the oxide and the free acid go

together to the positive electrode. This can easily be verified by means of a U-tube (Fig. 186), in which is placed the solution, and each arm of which has been put in communication, by a platinum wire, with one of the poles of a battery. Bubbles of oxygen may be seen to be liberated on the positive wire, while a red deposit of copper covers the other wire. If, in this experiment, wires or plates of copper were used as electrodes, then the liberated disengaged oxygen would unite with the metal of the positive electrode, forming oxide of copper, which, combining with the sulphuric acid set at liberty, forms fresh sulphate of copper, so that the solution remains always in nearly the same state of saturation.

We shall find this property of solution of the anode utilised in electro-plating where it is important to maintain constant the composition of the metallic baths. The electrolysis of an alkaline salt

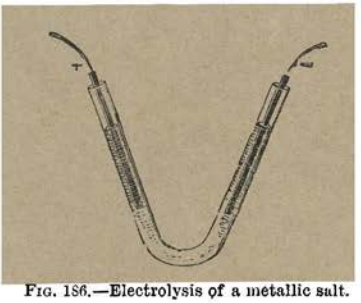

FIG. 186.—Electrolysis of a metallic salt.

only differs from that of metallic salts by a secondary chemical reaction easy to explain. Let us consider a salt of soda, the sulphate, and let us put its solution into a U-tube, after having coloured it with syrup of violets. As soon as the current passes, the solution is seen to be coloured red at the positive pole, and green round the negative electrode. Bubbles of oxygen and hydrogen are disengaged from both poles as in the decomposition of water. The metal does truly go to the negative pole, but the sodium as fast as it is produced decomposes the water, forms soda with its oxygen, and leaves the hydrogen free. As for the acid, it goes with the oxygen of the oxide to the anode.

There is in the electrolysis of water, or in any other binary compound, a fact worthy of remark: it is, that though decomposition appears to occur solely in the neighbourhood of two electrodes, or in

contact with them (for it is only at these points that gaseous bubbles are disengaged, either of oxygen or hydrogen), yet the rest of the liquid mass conducts the current without undergoing chemical change. This is how the apparent anomaly is accounted for. Let 1, 2, 3, 4, 5, 6 (Fig. 187), be a row of molecules of water situated between the electrodes; when the current passes all the molecules without exception are decomposed into their two elements, O, H, oxygen and hydrogen. The atoms of oxygen all tend towards the positive electrode; those of hydrogen (of which, according to modern views, there are *two* combined with each one of oxygen), on the contrary, are directed towards the negative electrode; but in this continuous movement the atom of oxygen in molecule 1 meeting the double-atom of hydrogen of molecule 2, a fresh combination takes place, and so forth all along the line, so that each molecule decomposed is, so to say, formed anew; there is no exception but for those atoms at the ends

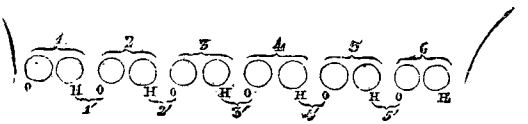

FIG. 187.—Transfer of molecules decomposed in the electrolysis of water.

of the row, namely atom O of the molecule 1, which disengages itself at the positive pole, and the double atom H of the last molecule at the other end which is disengaged at the negative pole.

This ingenious but somewhat too mechanical theory, due to the Swedish philosopher Grotthuss, based on the mobility or free transport of the molecules of electrolytes, agrees with the general fact that electrolysis does not show itself if the body is not in a liquid state; or if it is sometimes seen in solid bodies, it is only in proportion to their fluidity.

In recent times this so-called theory of Grotthuss has been modified by Clausius and by Williamson, in order to take into account the obvious fact that the molecules of a liquid are not standing still in rows, but are in incessant movement. Clausius's views are thus set forth in Maxwell's *Electricity*, Vol. I., p. 347:

"Clausius, who has bestowed much study on the theory of the molecular agitation of bodies, supposes that the molecules of all bodies

are in a state of constant agitation, but that in solid bodies each molecule never passes beyond a certain distance from its original position; whereas in fluids a molecule, after moving a certain distance from its original position, is just as likely to move still further as to move back again. Hence the molecules of a fluid apparently at rest are continually changing their positions, and passing irregularly from one part of the fluid to another. In a compound fluid he supposes that not only the compound molecules travel about in this way, but that, in the collisions which occur between the compound molecules, the molecules of which they are composed are often separated and change partners, so that the same individual atom is at one time associated with one atom of the opposite kind, and at another time with another. This process Clausius supposes to go on in the liquid at all times, but when an electromotive force acts on the liquid the motions of the molecules, which before were indifferently in all directions, are now influenced by the electromotive force, so that the positively charged molecules have a greater tendency towards the kathode than towards the anode, and the negatively charged molecules have a greater tendency to move in the opposite direction. Hence the molecules of the kation will, during their intervals of freedom, struggle towards the kathode, but will continually be checked in their course by pairing for a time with molecules of the anion, which are also struggling through the crowd, but in the opposite direction.

"This theory of Clausius enables us to understand how it is that whereas the actual decomposition of an electrolyte requires an electromotive force of finite magnitude, the conduction of the current in the electrolyte obeys the law of Ohm, so that every electromotive force within the electrolyte, even the feeblest, produces a current of proportionate magnitude."

[Still more recently Hittorf has advanced the view that the separated atoms or ions each possess a certain specific velocity, hydrogen atoms travelling through the liquid at a different rate from copper atoms, or gold atoms, or iron atoms, and these velocities have been measured by Kohlrausch. It is quite certain that Grotthuss's mechanical theory is insufficient to explain all the facts: for example it does not explain why, when a metal is being deposited from its solution, the liquid in the immediate neighbourhood of the

kathode becomes impoverished of metal. It should not do so if it were true that a regular interchange of atoms all along the line brought up the metal atoms as fast as they are deposited at the end.—ED.]

§ 2.—*Faraday's Laws.*

The name *Voltameter*, given by Faraday to the apparatus which is used for the decomposition of water or other binary compounds, indicates clearly that there exists, between the phenomena of electrolysis and the current of the battery which produces them, a constant relation which may serve to measure the latter. The illustrious English philosopher discovered, in fact, the laws which regulate these phenomena, and justified, as we shall see, the name just mentioned.

These laws are three in number.

We shall limit ourselves in speaking of them by saying briefly how they are verified by experiment.

The first law relates to the equality of chemical action in all parts of the circuit. To verify it, it is merely requisite to include in the circuit a certain number of voltameters, and to gather and measure separately the gases which are disengaged in each of them. The same is done for the gas which proceeds from the chemical reaction going on in the midst of each element of the battery.[1] It is then found that, in the same given time, the quantities of hydrogen evolved in each interposed voltameter in the circuit are equal, and it is the same with the hydrogen evolved at the copper plate in each cell of the battery. The result is the same even when in the different voltameters the water is rendered of different conductive power by addition of different proportions of acid, or by adding different substances, salts, acids, alkalis. In short, this law remains true whatever the electrolyte may be which is subjected to the action of the current; in each voltameter, or in each element of the battery, you find deposed or disengaged at each pole, by the same current

[1] In this case a Smee's battery which gives off hydrogen gas should be employed.

in the same time, quantities of matter which are chemically equivalent.

The first law discovered by Faraday may then be thus worded :— *The electrolytic action of a current is equal at all points round the circuit.*

Suppose that a current of given strength, after having traversed a first voltameter, is divided, by a branch being made in the con-

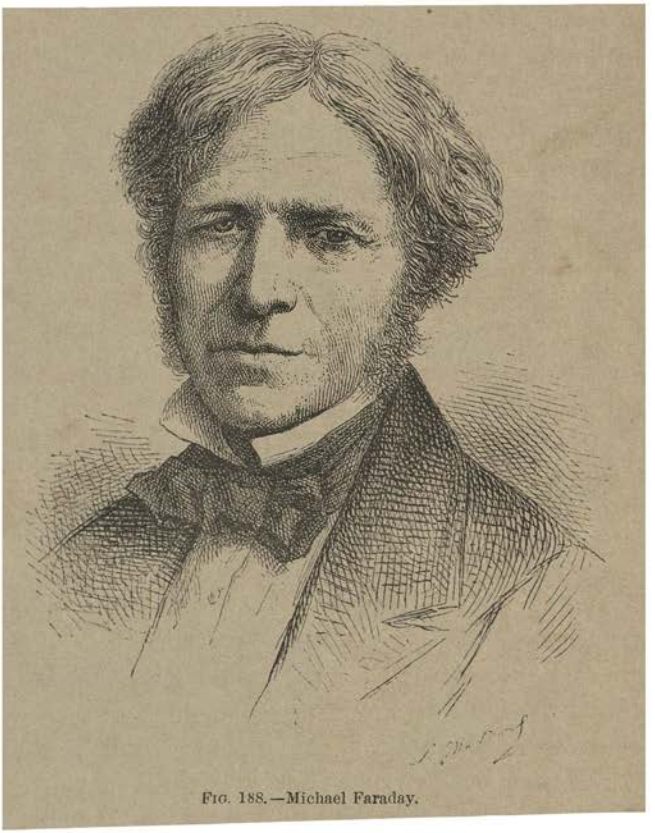

FIG. 188.—Michael Faraday.

ducting wire of the circuit, and after being thus split into two currents, traverses two voltameters identical with the first. Then this is what experience shows to occur in this case. If the two voltameters which receive the divided currents present the same resistance to the passage of the current, and in consequence are traversed each by half of the whole current, you will find in each of them half the quantity of

disengaged gas that there is in the first voltameter; if they offer unequal resistance the gas collected will not be in equal quantities, but their sum will always be equal to that of the disengaged gas in the voltameter traversed by the current before its division. So the total quantity of gas decomposed is in proportion to the total quantity of electricity which the current furnishes.

In measuring by the help of instruments, which we shall describe later on, the strengths of different currents, or the variable strength of the same current, Faraday recognised that the quantities of gas disengaged during the same time are in proportion to the strength of the currents.

The second law of electrolysis may then be worded thus:—*The quantity of gas disengaged in a minute is a standard measure of the average strength of the current during that minute; and the total quantity of gas evolved is the measure of the total quantity of electricity that the current has conveyed round the circuit.*

The third law discovered by Faraday determines the proportion of electrolysed quantities in the same current, when substances chemically different are submitted to its action. Suppose, for example, that the current of a battery traverses a series of vessels containing the following electrolytes: water, fused iodide of lead, fused chloride of tin, fused chloride of silver; then it can be shown that for each 32·5 milligrammes of zinc dissolved in any one of the elements of the battery there is produced

1	milligramme	of	hydrogen,
8	„	„	oxygen,
103·5	„	„	lead,
127	„	„	iodine,
59	„	„	tin,
35·5	„	„	chlorine,
108	„	„	silver.

Now these numbers 32·5, 1, 8, 103·5, 127, 59, 35·5 are no other than the chemical equivalents of the elements. Whence this law, the importance of which there is no need to point out:—

When the same current acts on many electrolytes the weights of the elements separated by electrolysis are in proportion to the chemical equivalents of these elements.

To continue, then, the quantities of electricity which are in movement in the current of a battery have a constant relation to the quantities of chemical action that result. Tyndall, speaking of the wonderful discoveries of his illustrious master, claims for the discovery of the law of definite electro-chemical decomposition an importance equally great with that of the law of definite combining proportions in chemistry.

§ 3.—*Thermo-electric Currents and Batteries.*

When you vary the temperature of a crystal of tourmaline between 10° and 150° it becomes electric; the two halves of the crystal take the two opposite electrical states, and you find in the middle a neutral zone. This state only continues, however, as long as the temperature varies; as soon as it becomes stationary the signs of electrification disappear. This property, which has long been known, is not, besides, peculiar to the tourmaline alone; it is met with in a certain number of other crystalline substances, such as topaz, silicate of zinc, spar, rock crystal, sugar, and it is for this reason that Brewster gave to these substances the name of *pyro-electrics*. A lately deceased electrician, Gaugain, having united by their poles of the same name a series of tourmalines thus electrified, recognised that the effect in producing a charge was considerably increased; but on arranging them end to end by their opposite poles, he found that the battery thus formed gave no more charge of electricity than each separately.

These experiments prove in every case that heat is a source of *charges* of electricity, as well as rubbing, chemical action, &c.

We shall now see that heat may serve for the production of electric *currents* in special heat batteries. Currents from this source are called *thermo-electric currents*. Their discovery dates back more than sixty years. In 1821 Professor Seebeck of Berlin made the following experiment: He bent a plate of copper into the form of three sides of a rectangle, the fourth side of which was constituted by a rod of bismuth soldered to the copper. Then heating one of the soldered joints by the aid of a spirit-lamp, Seebeck found that this operation determined the production of an

electric current going as the arrow points in Fig. 189 from the heated junction to the cold one by the bent copper plate. On cooling the same junction you also obtain a current, but in the opposite direction, and in both cases its intensity depends on the difference of temperature of the soldered junction of the two metals. To investigate the currents thus generated, the Berlin philosopher made use of the then recent discovery of Œrsted, that the electric current might produce a deflection of the magnetic needle. In Fig. 188 you may see between the two parallel sides of the rectangle of copper such a needle mounted on a pivot. In making the experiment, the rectangular metal frame should be set nearly in the plane of the magnetic meridian. As soon as there is a difference of temperature in the joints the current shows itself by a notable deviation of the magnetized needle.

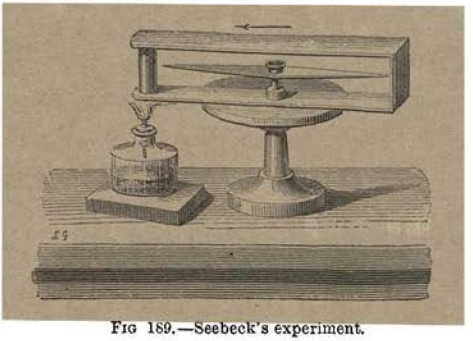

FIG 189.—Seebeck's experiment.

Thermo-electric currents have since 1821 been the object of very important researches. It was known from the first that they could be produced with any two different metals, and that their direction and intensity depend on the nature of the metals at the junction. For example, the current which in Seebeck's experiment goes from the hot joint to the cold by the copper is found to go in a contrary direction if antimony is substituted for bismuth.

Becquerel arranged a series of metals in such an order that the current set up at the heated junction of any two metals on the list goes from the metal which follows to that which precedes it in the series.

Becquerel's series is :—*Antimony, iron, zinc, silver, gold, copper, tin, lead, platinum, and bismuth.*

Antimony and bismuth, which are respectively the most highly negative and most highly positive in this list, give a higher thermo-electromotive force than any other pair of metals.

According to Becquerel, when one junction of a metal pair remains at 0° C. and the temperature of the other is not higher than 40° or 50° C., the intensity of the current is in proportion to the difference of temperature between the two junctions; but beyond 50° it increases less and less, until it becomes insensible at a point which depends on the nature of the two metals and on the mean temperature of their hot and cold junctions. The mean temperature at which the pair gives no current at all is called *the neutral point* for that pair. It is about 275°C. for a copper-iron cell, nearly 225° for a zinc-silver cell, a little above 150° for a gold-zinc one. As an example, iron and copper give no current if one of the junctions is maintained at 400° whilst the other is at 150°.

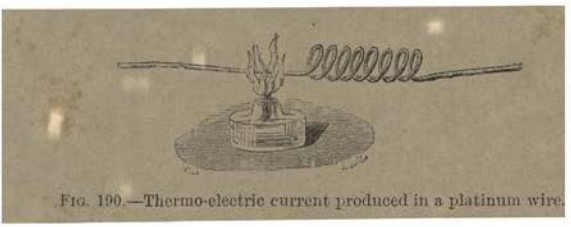

FIG. 190.—Thermo-electric current produced in a platinum wire.

Thermo-electric currents are obtained also when the circuit, instead of being formed of two different metals, consists of only one metal. Seebeck discovered this fact for metals with a crystalline structure, like antimony, bismuth.

But Becquerel also obtained currents by the aid of homogeneous metals, only it is necessary that from one part to another of the heated point the propagation of the heat in the metal should be unequal in the two directions, in consequence of some difference in the structure or form of the metal. Thus, when you take a platinum wire in which a knot has been made, or a portion of which has been twisted into a coil (Fig. 190), a current begins as soon as a point of the wire near the coil or the knot is heated.

The same phenomenon has been confirmed by Sturgeon and by Magnus in a continuous conductor—in a steel bar, for example, one part of which has been hammered or rolled, whilst the other has been annealed.

What is the cause of this production of electric currents ? How does the heat set up, between the two parts of the circuit, differences of potential which determine the production of the currents observed ? According to Becquerel, the propagation of heat in any conductor whatever would be constantly accompanied by movement of electricity. When the circuit is homogeneous from one point to another of the heated part, the electro-motive forces evoked are in contrary directions and of equal intensity, and therefore neutralize each other ; if there is a difference of structure, one of them masters the other, and this predominance is observed by the action of the galvanometer.

According to Le Roux, thermo-electric phenomena are caused by the electro-motive force which is developed by the contact of two heterogeneous substances : this force increases with the temperature ; other electro-motive forces, having their place in the mass of each

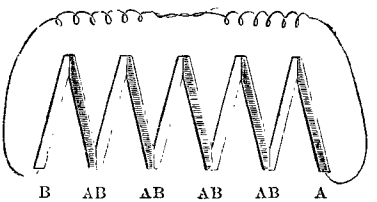

FIG. 191.—Element of Nobili's thermopile.

substance, when the temperature is not uniform, concur to produce thermo-electric effects.

The facts we have described have been applied in the construction of special instruments, to which have been given the name of *thermo-electric piles*, or briefly, *thermopiles*. We will describe some of these apparatus, which are, however, little used except for the study of the effects of radiant heat, or of differences of temperature in particular circumstances.

Nobili's thermopile is formed in the following way : A series of bars of antimony AAA, soldered end to end with bars of bismuth BBB, of the same length, is arranged (Fig. 191) so that the alternate junctions are on opposite sides, those of odd number on one side, those of even number on the other. In joining this series by two wires which come from the end bars, you have a circuit in which an electric current begins as soon as there is a difference of temperature between

two sets of junctions of the soldered bars. Thus, in Fig. 191, the junctions at the top are the first, third, fifth, &c., of the series, whilst the second, fourth, sixth, &c., junctions are in the bottom row. If the top row of junctions is either warmer or colder than the bottom row of junctions, a current will be set up in the circuit. The compound thermopile consists of a considerable number of elements of this kind united in a bundle in the form of a rectangular prism (Fig. 192), the two opposite faces of which must contain, one, all the odd junctions, the other, the even junctions. Two terminal screws placed at the two side faces of the prism, communicating one with the first bar of bismuth, the other with the last bar of antimony, may be regarded as the "poles" of this battery.

When Nobili's thermopile is used for researches on radiant heat

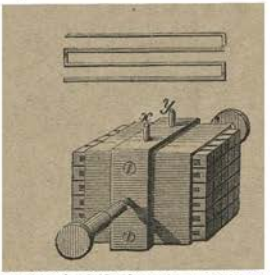

FIG. 192.—Arrangement of the bars in a compound thermopile.

the two poles are joined to a galvanometer (Fig. 193); the faces of the pile are protected from air currents or accidental changes of temperature by square brass caps, furnished with lids that can be opened or shut at pleasure. As soon as a source of heat begins to shine on one of the faces of the pile a current is started, and you will notice a deflection in the needle of the galvanometer. The direction of the deviation depends on the face that is heated, and its amount measures the amount of heating due to the heat-waves which have fallen upon the surface of the pile. The thermopile thus arranged is an instrument of great sensitiveness; it is sufficient by touching one of the faces with the finger, or by blowing a puff of warm air against it, to cause a very energetic deflection of the needle. The strength of the current, other things being equal, is proportional to the number of the junctions, that is to say, to the number of elements of the pile:

it is for this reason the name *thermo-multiplier* was at one time given to Nobili's apparatus.

A very simple instrument was devised by Peltier for the purpose

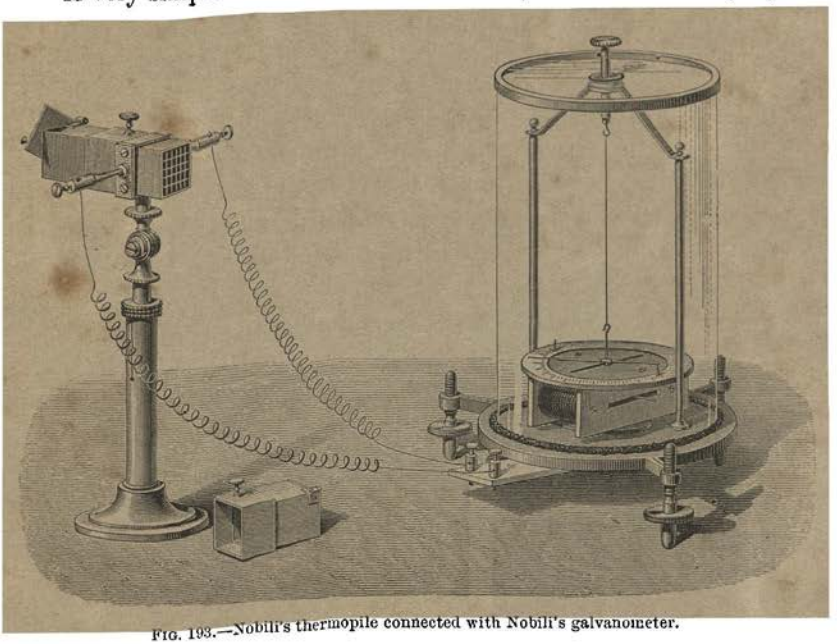

FIG. 193.—Nobili's thermopile connected with Nobili's galvanometer.

of observing feeble variations of temperature when they occur in a small object such as a metal rod or thin metal plate for example.

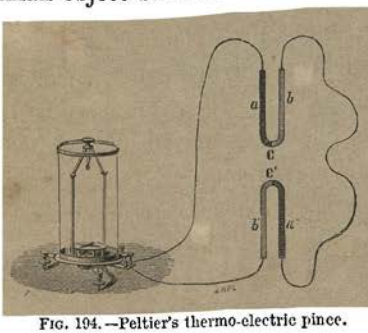

FIG. 194.—Peltier's thermo-electric pince.

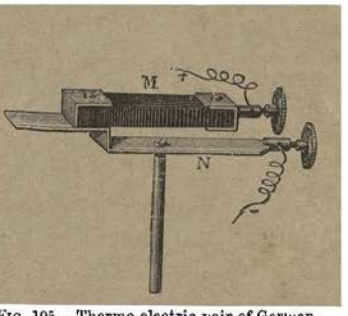

FIG. 195.—Thermo-electric pair of German-silver and sulphide of copper.

Two pairs ($a\,b$, $a'\,b'$) of antimony and bismuth have their junctions turned towards each other at $C\,C'$. The two pairs are joined together on one side by a wire, on the other they communicate with a galvano-

meter. If a body to be experimented upon is placed between the two junctions, every variation of temperature, heating or cooling, will give rise to a current, the direction and strength of which are indicated by the deflection of the galvanometer needle. To measure the temperature of the internal regions of a living body, a thermo-electric probe is used composed of two fine needles of steel and platinum, or of steel and German-silver, soldered together at their points. Fig. 195 represents a thermo-electric element, and Fig. 196 represents a battery of elements arranged together. This type, which is remarkable for its energy, was invented by M. Edmond Becquerel. In Fig. 195

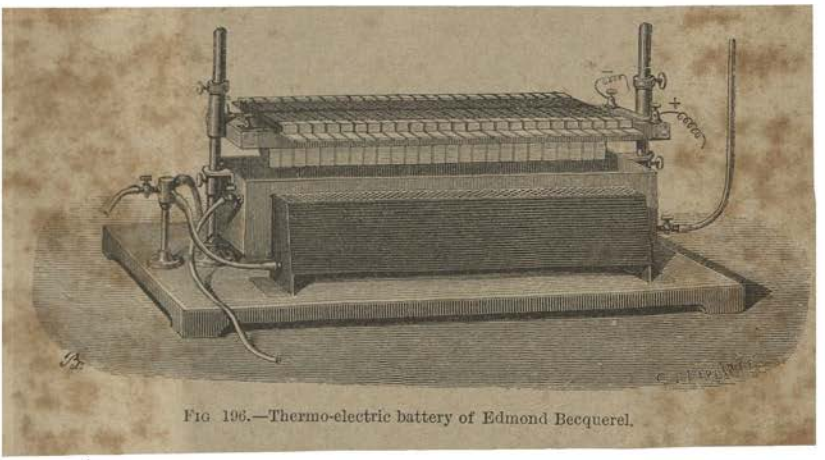

FIG. 196.—Thermo-electric battery of Edmond Becquerel.

M is a bar of artificial sulphide of copper soldered to a plate of German-silver, N. The elements are united in a rectangular frame, and the temperature of the junctions is raised by gas. A pile of thirty or forty elements thus formed has an electro-motive force strong enough to decompose water. This battery can also be used in telegraphy. In recent years thermo-electric generators have been devised by Nöe and by Clamond, having much larger numbers of elements. In the best of these the two materials in the element are nickel and an alloy of zinc with antimony.

§ 4.—*Secondary Batteries and Currents.*

We have seen that one cause of the weakening of currents in the early forms of battery was the existence of secondary electro-motive forces, resulting from the presence on the metal plates of the cells of films of gas or deposits of an active chemical nature. Becquerel showed how to obviate these opposing forces by adding to the cell a second liquid, separated from the first by a porous partition, the liquid chosen being of such a chemical nature as to absorb the gas or other active substance which would otherwise have been deposited on the electro-negative plate. Thus arose the "constant" cells described in § 3 of Chapter VI., p. 282.

The existence of secondary currents was discovered by Ritter in 1803. Having submitted to the action of a Volta's pile another pile formed only of discs of copper, separated by moist cloth, he remarked that this second pile, though inactive by itself, gave in its turn an electric current, in the opposite direction to the current of the first pile.

This current was of but short duration, and the electro-motive force was lower than that of the pile used in charging it. In 1826 De la Rive also found that a secondary or inverse current could be obtained from plates of platinum upon which oxygen and hydrogen had been disengaged in the experiment of the decomposition of water by a battery. This phenomenon took the name of *polarization of the electrodes*, and the current itself that of *current of polarization*.

After that, secondary currents were the object of many researches made by physicists, among whom we mention Faraday, Grove, Wheatstone, Poggendorff, E. Becquerel, and Gaugain. In 1859 M. Gaston Planté studied the influence of different metals and different liquids on the production of secondary currents, and on their intensity. Since that date the question has assumed great importance, having received scientific and practical applications, which have been largely the consequences of the researches of this acute observer.

He experimented on voltameters with wires of copper, silver, tin, aluminium, iron, zinc, gold, and platinum, and for each of them varied the nature of the liquid into which the electrodes were placed. He found "that all the metals oxidizing at the positive pole of the

cell, the secondary current, obtained after the interruption of the primary current, was as much more intense as the oxidation was more complete, if the oxide formed remained adherent and insoluble in the acidulated liquid of the voltameter." Even gold and silver did not resist the action of the oxygen of the pile; they were covered with dark deposits of oxide, and furnished an energetic secondary current. Platinum did not oxidize, it is true, in a visible manner, but the secondary inverse current was of shorter duration than that of the metals which were covered with a layer of adherent oxide; an effect which was explained by the rapid decomposition of the oxygenated water produced round the positive electrode of the voltameter. The action of the hydrogen was, on the other hand, stronger with platinum than with all the other metals, for the electrode around which this gas was disengaged furnished, with another neutral electrode, a more intense secondary current than when any other metal was employed.

The most important result of these interesting researches is that which assigns the greatest intensity to the secondary current produced by a voltameter with electrodes of lead, and dilute sulphuric acid as the liquid. Measuring the electro-motive force developed in such a voltameter, after the rupture of the primary current, Planté found that it was equal to about one and a half times (more exactly 1·48 to 1·49) that of the most energetic voltaic element, such as a Grove or Bunsen. This suggested the idea of constructing secondary cells, and uniting them in a battery, so as to store up or *accumulate* the work of the voltaic pile, in the same way that static electricity is condensed by the aid of conductors of great surface, separated by an insulating material. Planté has given to apparatus based on this principle various forms. We will describe one which possesses his various improvements.

Two long wide plates of lead, separated from each other by two pairs of india-rubber bands five millimetres thick, are rolled in a spiral. They terminate in two projecting lugs destined to receive the terminals. The spiral plates are kept together by little cross pieces of gutta-percha, then they are put into a cylindrical glass vessel filled with water acidulated with one-tenth sulphuric acid. The lid of the vessel is made of vulcanite, and carries two metal clips, to be used after the cell has been charged. The ends of the two plates of lead of the cell communicate by the aid of the two clips, G H

(Fig. 197), with the poles of a battery formed of two small Bunsen cells, as well as with two small plates of copper, M and M'. One of these is in constant communication with the clip A'; the other, by the aid of a button, B, and of a small plate of copper, R, forming a spring, can be put into communication at will with the clip A. These two clips are for holding wires such as shown at F, which are to be heated by passing the secondary current through them.

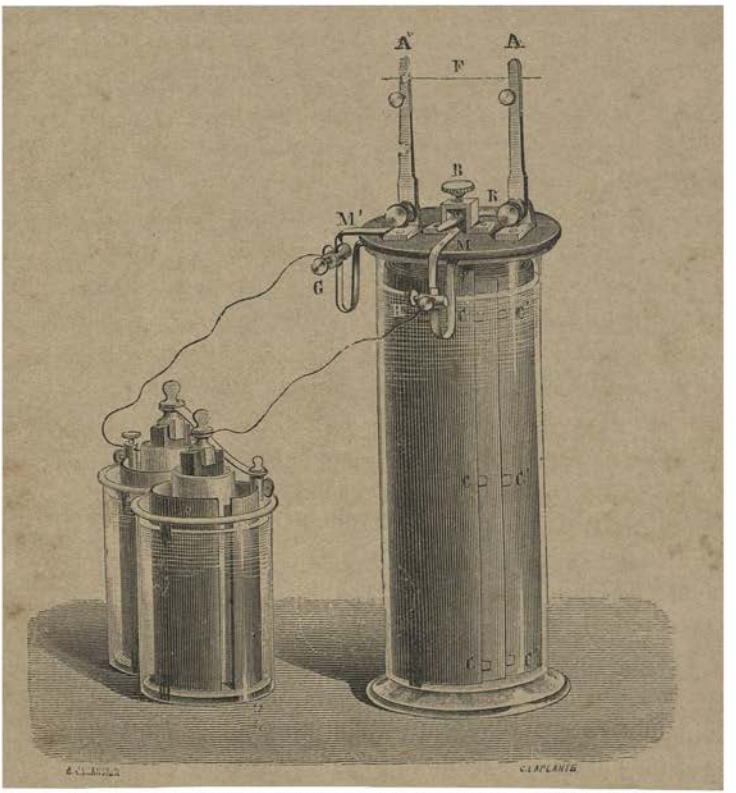

FIG. 197.—Secondary cell of Planté, being charged from two Bunsen cells.

A secondary cell thus made does not at first possess its full power of accumulating currents. It needs to be prepared, or "*formed*," according to the expression of the inventor. "When a secondary cell is new," says Planté, "when it receives for the first time the action of the primary battery, it only gives effects of short duration."

But if you charge it several times, first in one direction then in the

other, for a sufficiently long space of time to produce the deposit of peroxide, first on one plate, then on the other, allowing it to rest several days between each charging to give the deposits time to set, then the secondary effects gain considerably in duration and strength.

A well-formed cell[1] will give discharges of relatively long duration, "sufficient, for example, to make a platinum wire of half a millimetre in diameter red hot for twenty minutes, and a wire of $\frac{2}{10}$ of a millimetre for more than an hour."

Besides, it keeps its charge for a very long time. A well-formed secondary cell which has been charged for some hours by the current from a primary battery, and which has been left to itself, without closing the circuit, for a week or even a fortnight, can still give a current strong enough to make a platinum wire half a millimetre in diameter red hot for some instants.

The secondary cells with electrodes of lead that we have just described, solve the problem of *accumulating* a certain quantity of electricity produced by a voltaic battery, but they cannot give an electro-motive force greater than that of the charging battery. To do this Planté constructed an apparatus in which the secondary cells after being charged in parallel can be united in series. Fig. 198 represents a secondary battery of twenty cells, arranged in two rows in a wooden frame, which has, at its upper part, a device called a *commutator*, C C', by means of which the cells can be connected up either in parallel or series. We shall see what is the reason for adding this commutator to the apparatus.

When it is necessary to charge the battery, the cells must be united in parallel so that the current of a Bunsen battery (always here made of two cells only) meets no greater opposing electro-motive force than that of one cell. When twenty cells are thus joined they act like a single cell having a surface twenty times larger than that existing on the plates of any one of the individual cells.

[1] "When a secondary cell is considered as sufficiently prepared, the intervals of rest of some months, far from being useful, as for the operation of preparation, would tend to increase the resistance of the cells, and to render the charging of them longer and more difficult. It is preferable then to charge them from time to time, or to maintain them always in charge by a feeble primary battery, in order to avoid the production on the surface of the positive plate, of a layer of protoxide or of sulphate of lead, a bad conductor."—G. Planté, *Recherches sur l'Électricité*, 1879.

The theoretical Figure 199, where each cell is represented by two plates, P_1P_2, P_3P_4, &c., indicates this mode of grouping "in *parallel*"; the plates of odd numbers, P_1P_3, communicate together and take a negative charge; also, all those of even numbers become positive.

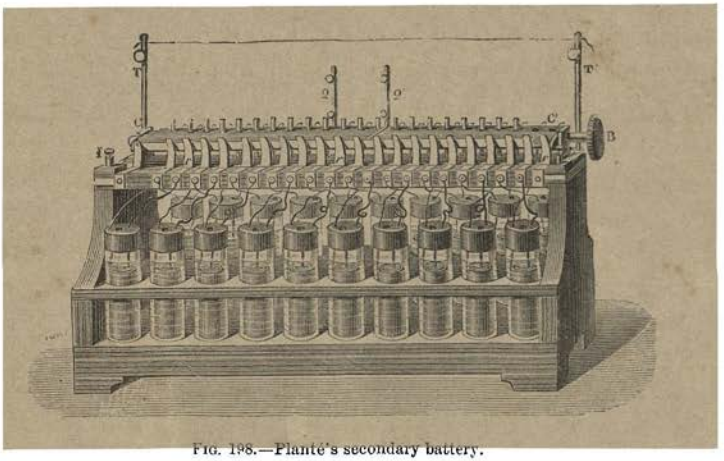

FIG. 198.—Planté's secondary battery.

In this way the current of the primary battery, which would be stopped by the interposition of twenty secondary cells arranged one after the other or "in *series*" (as is seen in the theoretical Figure 200), can traverse the system, and the battery is charged. Once it is

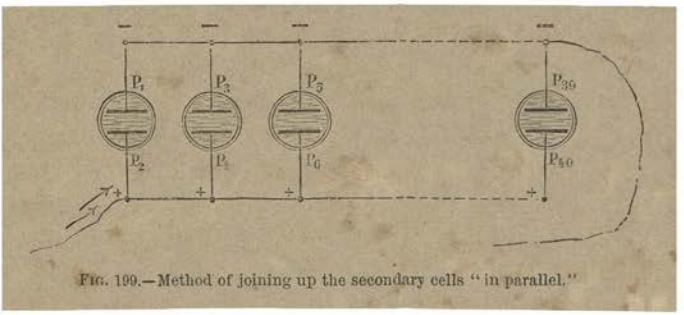

FIG. 199.—Method of joining up the secondary cells "in parallel."

charged, you turn the commutator. This apparatus cuts off communication with the primary battery, and after disconnecting the twenty secondary cells connects them up again "in series"; and as the electro-motive force of each of them is about (as we have seen) one and a half of a Bunsen cell, there result, in the discharge,

effects equal to those that would be obtained with a Bunsen battery of thirty cells.

One word now about the commutator which renders possible this double operation. It is a wooden rod furnished with two longitudinal strips of copper, and pierced by a series of metal pegs. When you turn commutator by aid of the button B (Fig. 198), so that the rod seen in diagram may have the position as in Fig. 201, one longitudinal strip, $g\ g'$, touches at once all the springs, like r, which communicate

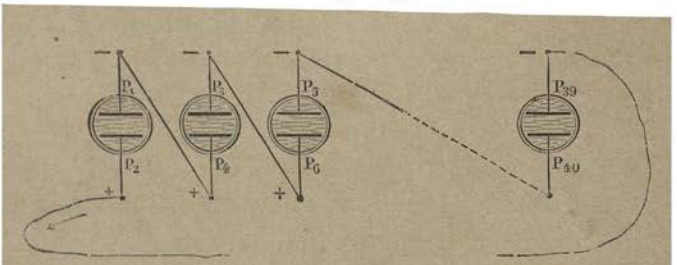

FIG. 200.—Method of joining up the secondary cells "in series."

with the plates on one side of the cells, the other strip, the springs r', which communicate to the plates on the other side: the cells then are joined in parallel. By turning the wooden rod at right angles to its first position, the pegs, as shown at $h\ h'$ (Fig. 202), touch these springs two by two, so that the cells are joined in series.

FIG. 201.—Position of commutator for joining "in parallel."

FIG. 202.—Position of commutator for joining "in series."

In Fig. 198 the commutator occupies the first position, that which it ought to have during the charge of the battery.

Later on we shall describe some of the remarkable experiments that the inventor of secondary cells and batteries has made by the aid of these powerful apparatus. We may conclude this subject by borrowing of Planté a comparison which will we think, show clearly, the importance of employing, as he did, currents which physicists before him had only thought of neutralizing. "Secondary cells," he

says, "work like an apparatus for transforming or accumulating the work of the voltaic cell, in the same way as those machines so much used in mechanics, and which, without being motors themselves, serve to accumulate or transform the forces. An isolated secondary cell, with a surface more or less great, may be exactly compared to a simple lever more or less long; the more complex system of the battery, composed of a certain number of secondary cells that may be discharged at will in parallel or series, is quite analogous to the machine known in mechanics under the name of a pile driver. It is known that in this machine, a heavy mass, raised up little by little to a great height by a series of successive efforts, is then let go, and gives out by its fall, under the form of one great blow, the greater part of the work bestowed upon it during a comparatively long time. In the secondary battery, the sum of the chemical actions produced by a feeble source of electricity distributed over a greater number of secondary cells develops a sum of electromotive forces which, when united by the closing of the circuit, restores, under the form of a current that is very strong but of short duration, the sum of the actions accumulated during all the time that the charge of the battery has lasted. The effects of quantity correspond to the fall of a heavy mass raised to a little height; the effects of electromotive force to the fall of a less heavy mass raised to a great height." [1]

§ 5.—*Planté's Rheostatic Machine.*

As we have just seen, Planté used his secondary cells and batteries for the accumulation and transformation of the work of the voltaic battery. His apparatus allows us to obtain at will temporary effects of either a large current at a small pressure (or electromotive force) or of a small current at a large pressure, in either case greatly in excess of those of the battery employed. Planté has also designed a new machine which he called a *rheostatic machine,* the object of which is quite different. Its action is as follows :—

The electromotive force of a battery (primary or secondary) *tends* to drive an electric current through the circuit. But if the circuit be

[1] *Recherches sur les Courants Secondaires et leurs Applications.* Treatise by Gaston Planté, Paris, 1874.

not continuous there can be no current; in that case all that the electromotive force can effect is to *charge* the open ends of the circuit, positively and negatively respectively. These charges can be conveniently taken upon plates of metal connected to the circuit; and the capacity of such metal plates to act as a condenser is greatly increased if they are placed near to one another with a layer of insulating material between them. Condensers so constituted, and so charged, may afterwards be discharged, and can furnish sparks and shocks. If many such condensers, charged to a certain potential, are united together in series to give their discharge, the potential with which the series will act is the sum of the separate potentials of the condensers. For example, if each of the separate condensers were so charged as to be able to give a spark $\frac{1}{100}$ of an inch in length, then fifty such condensers, separately charged, united in series and then discharged would approximately give a spark half an inch long. Flowing *currents* are thus made to yield stationary *charges*, and the stationary charges are then caused to give a sudden and powerful *discharge*.

M. Planté having frequently proved that secondary batteries of 600 to 800 cells are capable of very rapidly charging a condenser made of an insulating plate of very thin glass, mica, gutta-percha, or paraffin, he was led to unite a certain number of condensers of mica covered with tinfoil, arranged them like the cells of his secondary batteries, and thus realised the ideal machine we have just mentioned.

Fig. 203 represents a rheostatic machine of eighty condensers, constructed after the model of those we have just described. The condensers are formed of plates of mica (18 centimetres by 14) covered with tinfoil, and are separated by sheets of ebonite which, whilst insulating them gives them also rigidity enough to enable them to be held up in a vertical position near each other. To the ends of each sheet of foil are fixed fine copper wires covered with gutta-percha, and are alternately connected to springs on the top of the box. All the odd sheets of foil are connected to the springs on one side, and the even sheets to the springs on the other side of the box. The commutator for changing the connexions of the condensers is an ebonite cylinder, 1 metre in length and 15 centimetres in diameter, furnished on two sides with longitudinal metal plates, and also

provided with a series of metal rods which cross through it transversely, exactly as in the commutators used (Figs. 201, 202) with the secondary batteries. This appliance allows the condensers to be joined

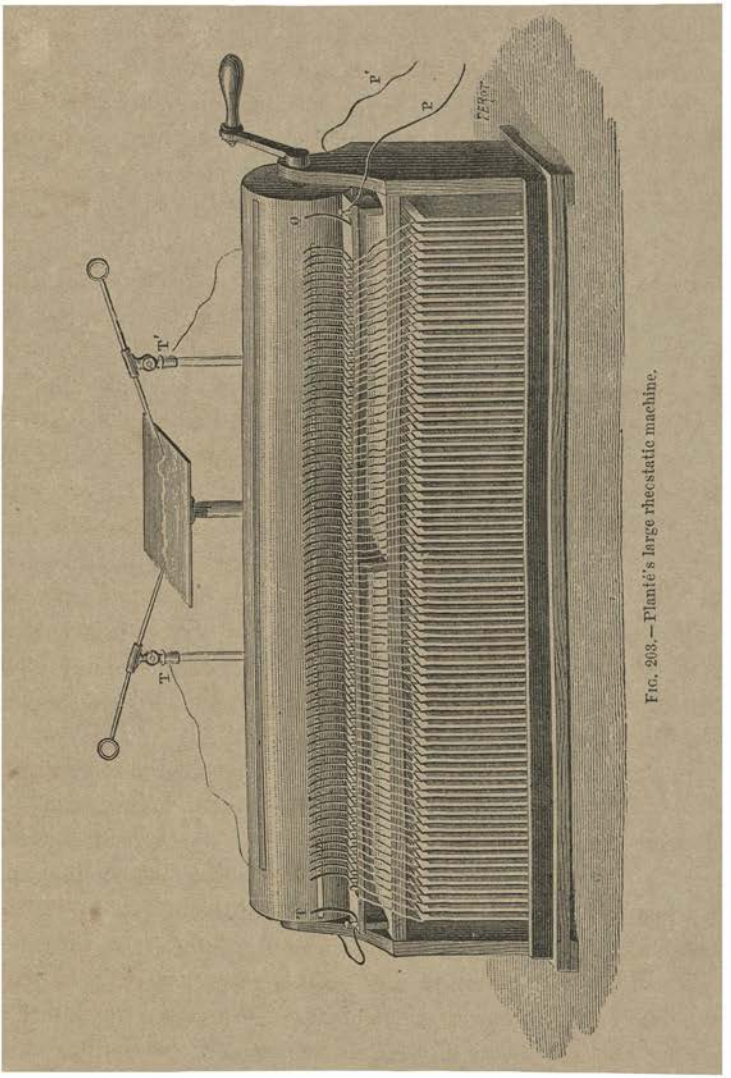

FIG. 203.—Planté's large rheostatic machine.

either in parallel or in series with one another, at pleasure. When the commutator is turned so as to present the two long metal bands to the springs communicating with the sheets of foil so that on one

side all the odd sheets of foil, and on the other all the even sheets are connected together, then all the condensers form one condenser only of great surface; it is charged by joining the ends P P′ to the poles of the battery. When, on the contrary, the cylinder is turned as the figure shows it, the condensers are united in series. The branches T and T′ of the discharger communicate with the bars of the two end condensers, and in this position the battery which has charged the machine is not included in the circuit. When the commutator is made to rotate, small sparks appear at all the points along the line where the metal bands meet the springs attached to the condensers to charge them in parallel, transforming the cylinder into a sparkling tube. Another line of sparks appears at the moment when all the condensers are united in series and the grand spark is produced between the terminals of the discharger.

If a column of distilled water is interposed in the circuit of the battery, the water seems to be decomposed in a continuous manner, whilst the machine is in movement. In reality, this decomposition takes place only at the moment when the sparks are produced in charging, for, during the discharge, the water tube as well as the secondary battery are out of the circuit.

The limited quantity of electricity stored up in the secondary battery wastes away little by little during the repeated charge and discharge of the condensers; but this waste is very slow, and each charge of the condensers, and consequently each discharge, corresponds to a very minute quantity of electro-chemical energy consumed in the battery.

Planté has succeeded, by augmenting the number of condensers and diminishing the thickness of the insulating plates, in making his rheostatic machines produce all the effects of ordinary frictional electric machines, and of induction coils, without employing batteries of more than 100, or even more than thirty to forty secondary cells. We shall describe some of these effects later on.

CHAPTER VIII.

ELECTROMAGNETISM.

§ 1. *Action of Currents on the Magnetic Needle.*

TWENTY years after the discovery of Volta's pile, a new fact of great importance was brought to light by Oersted, professor in the University of Copenhagen. This accomplished *savant* found that the electric current acted on the magnetic needle. For a long time there had been a suspicion of the existence of a relation between magnetic phenomena and electricity; people had remarked the occurrence of perturbations by the mariner's compass on ships struck by lightning, or when their masts presented the phenomenon known by the name of *St. Elmo's fire.* It was known that discharges of batteries of Leyden jars affected magnetic needles placed near the apparatus. But these facts only gave vague ideas on the relation mentioned above.

In 1820, the year after that in which Oersted made his discovery, Ampère studied and described the laws of this action, and showed besides that the currents themselves acted on currents, and later, Arago, Davy, and Sturgeon discovered the magnetising of steel and soft iron under the influence of the current from a battery. The experiments of these men were so many points of departure for a multitude of new experiments, which in a short time completely changed the aspect of this part of the science by showing that magnetism and electricity are different manifestations of the same cause. We shall see later on that the same discoveries which revealed the true nature of magnetism, and caused so much progress in theory, have not been less fruitful in ingenious and useful applications.

We will return to the experience of Oersted. Let us consider a magnetised needle suspended on a pivot, and movable in a horizontal plane. We know that it places itself in the magnetic meridian, making a constant angle with the geographical meridian lying north—south. Place parallel to the needle, above, and at a little distance from it, a metallic wire, the ends of which are connected to the terminal of a battery. As soon as the current passes, the needle is observed to deviate from its position; it quits the magnetic meridian, and tends to set itself across the current. Instead of placing the wire above the magnetic needle, let us suppose it to be placed at the same distance below; the needle turns about and places itself afresh across the current, but deviated to the other side.

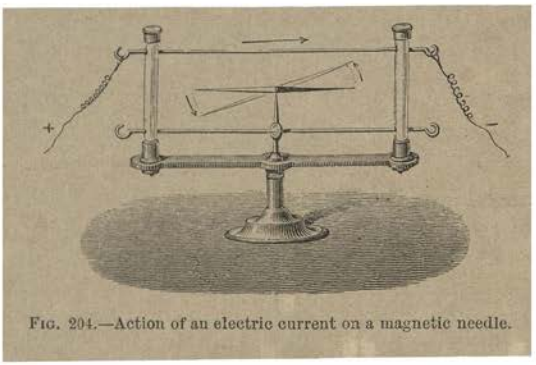

FIG. 204.—Action of an electric current on a magnetic needle.

Let us repeat the two experiments, but change the direction of the voltaic currents. Then we find that if the current flows first from south to north over the needle, the north-pointing end of the needle turns westward; but on reversing the current so that it flows from north to south over the needle, the north-pointing end of the needle deviates eastward. In fact, the reversed current produces magnetic deviations precisely opposite to those which are produced by the direct current.

A current flowing in a vertical wire, up or down, will act similarly upon a magnetic needle that is pivoted and balanced so as to come to rest perpendicularly. Oersted found that in every case the current in the wire tends to make the needle set at right angles to the line of current, as if the north pole were dragged one way round the current and the south pole the other way. Oersted expressed his discovery

by saying that the electric current acts "in a revolving manner" on the magnetic needle.

Ampère succeeded in expressing in one short statement the law of these deviations. He conceived the ingenious idea of personifying the current, and to figure it by a person lying along the wire, and whose face is in all possible positions always turned towards the magnetic needle. The current which flows, as we know, from the positive pole of the battery to the negative pole through the wire, is supposed to enter at the feet of the person, and to go out at his head. This being granted, the current has a right, and a left, which are those of the person himself; then comes the simple statement by which Ampère has combined all the different cases which the experiments of Oersted furnished: *When an electric current acts on the magnetic needle, the north pole of the needle is urged towards the left of the current.*

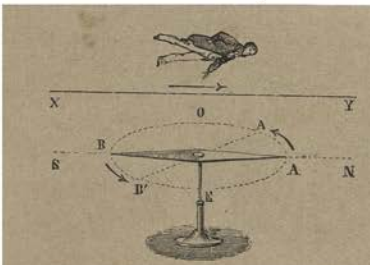

FIG. 205.—Deflexion of needle caused by current above it.

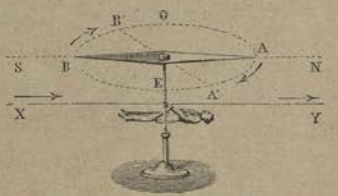

FIG. 206.—Deflexion of needle caused by current below it.

The current in the two Figures 205 and 206 goes parallel to the needle, and from south to north. In the case of the current above the needle the north pole A deviates to A′ at the left of the current, that is to say, towards the west; when the current passes below the needle, the deflexion is still toward A′ to the left of the current, but then the pole goes towards the east.

[Another rule, easily remembered, is that when the current flows from *south* to *north over* the needle, the deviation of the north pole is to the *west*. The initials of the four words in italics make up the word S-N-O-W.

Another rule, suitable for the case of currents flowing round coils, is that the direction of flow in the current and the direction of the force on the north pole of a magnet are associated together like the rotation and the translation of a right-handed screw: that is to say,

a right-handedly-flowing current is accompanied by a forward thrust on the north pole of the needle in the coil. There are many other mnemonic rules, but all can be deduced from Ampère's simple rule.]

When the current is vertical, as in Fig. 207, it may be ascending or descending, and will tend to send a north pole to its left, or a south pole to its right. In the case which Fig. 207 represents, you see the north pole is deflected to the east, that is is to say, to the left of the current. We shall leave to the reader to find the direction of the deviation of the needle in the other cases; it is easy, thanks to Ampère's rule.

The laws which regulate these deflections have been studied by Biot and Savart, and by Laplace. We may simply remember this fact, that the influence of the current depends on its strength (and therefore on the electromotive force of the battery and on the

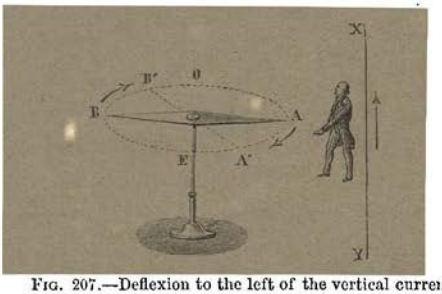

FIG. 207.—Deflexion to the left of the vertical current.

resistance of the circuit), and it diminishes according as the distance from the needle increases. For the case of an indefinitely long straight conductor carrying a current near a magnet pole, *the force which the current exerts on the pole is proportioned directly to the strength of the current and to the strength of the pole, and is inversely proportioned to the simple distance from the pole to the conductor.* If instead of taking a long straight conductor one were to consider the electromagnetic effect due to one short element of the current, one would find the same law as for other physical forces that act from point to point, namely that the force varies in inverse ratio to *the square of the distance.*

It must not be forgotten that in the presence of a voltaic current the needle is subject to two influences at once, that of the current

itself, and that due to the earth. The deviations observed then are the effects resulting from these two simultaneous actions. If by any means whatever we could direct the magnetic needle independently of the action of the earth (in which case we should speak of it as an astatic needle), the current would then always send the needle to a right angle, whatever might be its strength. In such a case the deflexion would indicate the presence only of the current, without proving anything about its strength; whereas if the magnetic force of the earth were continually striving to set the needle in one direction, while the current tended to deflect it in another, the resultant position taken up by the needle will obviously depend on the strength of the current. We can now see how the action of electric currents on the magnetic needle has been applied to construct an apparatus which serves at once both to demonstrate the presence of the currents —even feeble ones—and to measure their strength.

§ 2.—*Measurement of the Strength of Currents: Galvanometers.*

Ampère was the first to use Oersted's discovery to measure the intensity of currents; but to Schweigger and to Poggendorff, working independently, is due the happy thought of multiplying the action of electricity on the magnetised needle, so as to detect the existence of the feeblest current. The instrument, then called the *multiplier*, is now termed the *galvanometer*.

Schweigger's multiplicator consists of a wooden frame on which is wound a number of turns of copper wire. The wire is covered throughout its length by an insulating substance, such as cotton, silk, or gutta percha, so that an electric current entering at one end of the wire and passing out at the other cannot pass from one turn to another, but must traverse the whole length, and therefore flow many times over and under the needle.

The frame is placed vertically on one of its sides, in the plane of the magnetic meridian, and there is placed inside a magnetic needle, freely suspended on a vertical pivot. Such an instrument is suitable for detecting, by the deviations of the needle, the existence of an electric current. For this it is only necessary to attach the ends of the wire of the multiplicator to the two terminals of a battery or of

any other voltaic circuit. As soon as the circuit is closed the presence of the current is shown by a deviation of the needle to a greater or less angle from the meridian. If we analyse that which occurs, we shall see how the action of the current is multiplied by the arrangement. In Fig. 209 let us think of one of the turns of wire round the frame: the current passes from M to N, then to Q, then P, and on to R, where it goes away from the needle. Now, if you refer to Ampère's

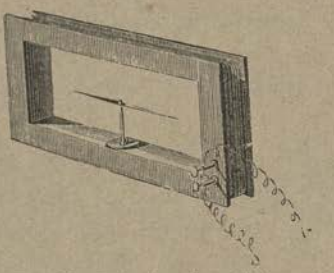

FIG. 208.—Schweigger's multiplier.

law, you will see that each of the four portions of the current tends to move the north pole a to a', that is, towards the east, or, if you will, towards the front of the figure; each one of the four portions acts like an independent current, like a finite portion of an indefinitely long straight current near the needle. The total deviation due to the action of all the four portions will therefore be more than if the

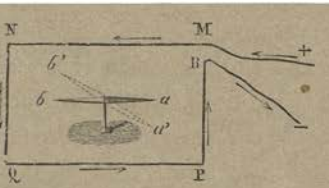

FIG. 209.—Concurrent action of the different parts of the wire in a coil of the multiplier.

current were only carried once over or once under the needle. Now if there are more turns of wire than one, in each successive turn the current acts afresh in the same way, and it is the same for all the turns successively, so that its influence on the magnetic needle is *multiplied* by the number of turns of the wire in the coil. Hence the name "multiplier" given to the instrument. The multiplication of the number of turns cannot be indefinitely increased, so that

the power of the instrument is necessarily limited. For though every added turn of wire adds to the multiplying power of the coil, it also adds to the resistance of the circuit and therefore tends to reduce the strength of the current. Where currents due to small electromotive forces, such as those generated in thermo-electric actions are to be measured, care must be taken to keep the resistance of the coil small also, a very few turns of very thick wire being appropriate. But to detect currents coming through circuits of very high resistance, such, for example, as the electro-physiological currents generated in the muscles of living creatures, great multiplying power is absolutely necessary, and the appropriate coil will be a very long one, consisting of thousands of turns of very thin wire.

The magnetic needle is here, as we have already said, acted upon by two forces—the directive action of the earth, by virtue of which it is placed in the magnetic meridian, and the action of the current,

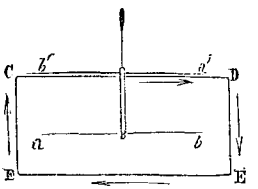

FIG. 210.—Astatic needles applied in the multiplier.

which tends to make it take a position perpendicular to the frame. The oblique position assumed by the needle is the resultant of these two actions. To render this deviation greater, and to give more power to the multiplier, Cumming, and afterwards Nobili, proposed to substitute for the magnetic needle an astatic system of two parallel magnetic needles $a\ b$, $a'\ b'$, but fixed to the same axis, so that their poles of the same name may be placed in an inverse direction (Fig. 210). The axis being suspended by a silk thread without any twist, if the needles have the same magnetic moments, the system will be astatic, that is to say, will remain in equilibrium, whatever may be the angle that it makes with the meridian. However a rigorously astatic system would not fulfil the aim proposed, which is to measure the intensity of currents by deviation, since then the deviation, as we have already said, would always reach the maximum of 90° whatever might be the feebleness of the current. But if one

of the needles, the lower one for example, has a slightly greater magnetic moment than the upper one, the system will continue to be influenced by the earth; this action will be very feeble, and therefore the action due to the currents will, if the needles of the system are themselves strongly magnetised, be relatively very powerful.

The name *galvanometer* is now given to all such instruments used for the detection and measurement of currents, whether they have astatic systems of needles or merely a single needle.

Fig. 211 depicts the form given to the astatic galvanometer by

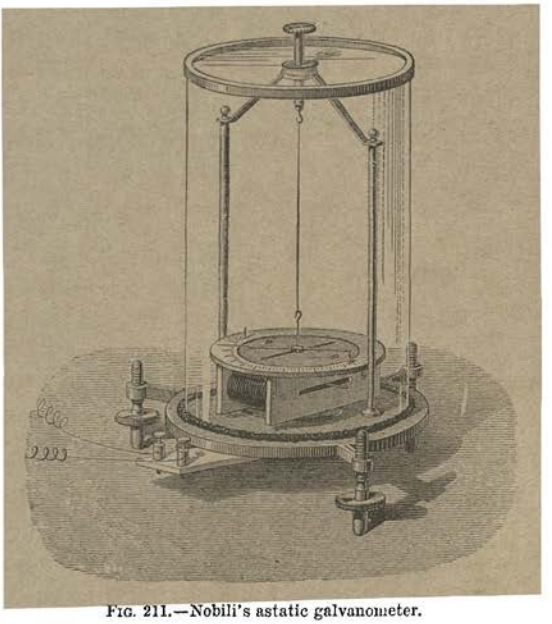

FIG. 211.—Nobili's astatic galvanometer.

Nobili. The coil is wound on a frame of ivory (or wood), on the top of which is a dial divided into degrees. Through the centre of the dial passes a thread of unspun silk by which is suspended the astatic pair of needles. The coil frame can be turned in the horizontal plane by the aid of a handle outside. In arranging the apparatus the coil is put into the plane of the magnetic meridian, and you can know that it is in that plane, when the zero of the graduation of the dial corresponds with one of the ends of the upper needle. Then you are sure that the coils of the copper wire are parallel with both the needles of the system. Below the frame is fixed a rectangular plate of ivory

or wood projecting under the base of the apparatus, and on this are borne two terminal screws respectively connected to the ends of the coil of wire. It is to these terminals that the wires from the battery or circuit are attached when it is desired to measure the direction and strength of the current. As soon as the circuit is closed and the current traverses the coils, you may see the upper needle deviate to the right or to the left of the position of equilibrium; the direction of this deviation indicates, according to Ampère's law, the direction of the current. The apparatus is furnished with levelling screws, so that it may be placed truly horizontal, and a glass shade protects the suspending thread and the needles themselves against air currents. The angle to which the needle is deflected depends upon the strength of the current and on the number of turns in the coil.

In all galvanometers the question has to be considered whether the scale-readings are proportional to the currents. If the needle goes round, say to 40°, does that indicate that 40 times as much current is flowing as would suffice to make the needle go round to 1°? That question is all-important; and, unfortunately, in the great majority of instruments the scale-readings are by no means truly proportional to the currents. It is, in general, true that for small deflexions, that is to say for deflexions not exceeding 15° on either side of the zero, the scale-readings are proportional; but generally beyond 15° or 20° on either side of zero the proportion fails to be true, for the scale-readings are *then* too small in proportion to the real currents. The reason for this is as follows:—The force which *tends* to deflect the needle is always, so long as the needle is considered in its zero position, exactly proportional to the number of ampères of current and to the number of turns of wire in the coil. Thus the force exerted by a current of 5 ampères flowing once round the coil will produce a force five times as great as a current of 1 ampère flowing once round. Equal forces precisely would be produced by a current of 5 ampères flowing round 1 turn, or by a current of 1 ampère flowing round 5 turns, or by $\frac{1}{2}$ ampère flowing round 10 turns, or by $\frac{1}{500}$ ampère flowing round 500 turns; and equal forces will always produce equal deflexions on the same instrument under similar conditions. But a double force does not produce a double deflexion simply because when the needle has already turned to an oblique position the leverages of the forces are not the same as they were;

the deflecting force due to the coil has now a reduced leverage, whilst the controlling directive force of the earth's magnetism has a greater leverage. In such cases then either a specially-constructed scale, having divisions that get closer together for the higher readings, must be substituted for a scale of degrees, or else a "calibration-table" must be calculated and drawn up to show the relative values or "calibres" of the scale-readings at the various parts of the scale. Special experiments are required to construct such a table for reference.

Melloni employed a method of calibration in which he made use of thermo-electric currents. Becquerel compared the strengths of two currents by sending them in contrary directions simultaneously through two wires coiled round the frame of the same galvanometer.

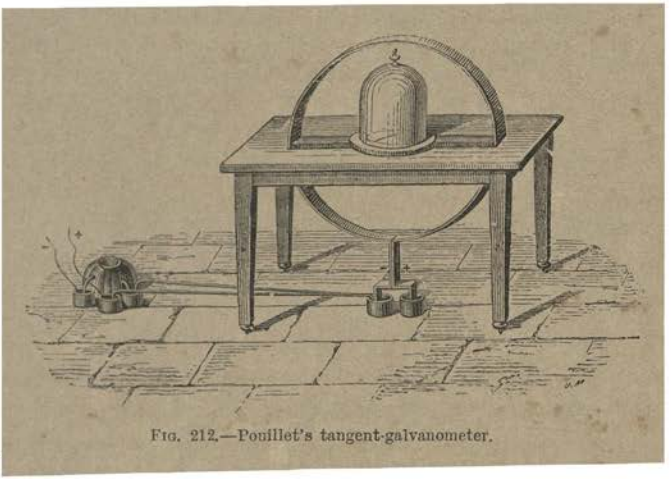

FIG. 212.—Pouillet's tangent-galvanometer.

He thus measured the difference of their actions on the needle, and for that reason he called the instrument so arranged the *differential galvanometer*.

To obviate the difficulties attending the special calibration of instruments, several special forms of instrument have been devised on particular plans such that the geometrical relations of the forces enable the relative strengths of the currents to be read off with utmost precision in terms of some known function of the angle of deflexion. Two of such instruments, the *sine-galvanometer* and the *tangent-galvanometer*, were devised by M. Pouillet. The description which follows is taken from that author.

"The tangent-galvanometer, which is shown in Fig. 212, is composed

of a large metal circle through which the current passes, for which purpose it is furnished at the bottom with two terminals which are put in communication with the two poles of the battery by means of two mercury cups. This circle is placed in the plane of the magnetic meridian. At its centre is a short thick magnetic needle, suspended by a torsionless thread, and bearing cross-wise an index long enough to pass over the divisions of the horizontal circle, which is graduated into degrees. As soon as the current flows around the vertical circle the needle is deflected according to the intensity of the current, and it is easy to show that the intensities of the currents are precisely proportional to *the tangents of the deviations which they produce.*[1] It

[1] The following is the proof: (Fig. 212) $a\,b$ is the position of the needle in the magnetic meridian, $a'\,b'$ that of the needle deflected by the action of the current, which necessarily exerts a force perpendicularly to the plane of the coil. Two forces contribute to maintain the equilibrium in this position of

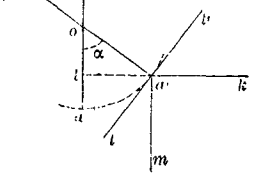

FIG. 213.—Construction showing how tangents of angles of deflexion are proportional to the deflecting forces.

deviation, one $a'\,m$ is the magnetic force of the earth, the other $a'\,k$ is that of the current. Both act on the needle, and it takes up such a position that their respective components $a'\,t$ and $a'\,t'$ resolved at right angles to the direction of the needle are equal. The first is proportional to sin a, and may be written T sin a, T being a constant dependent on the terrestrial force and on the needle. The second is proportional to cos a, and may be written I cos a, I being the intensity of the current. You will have then as equilibrium :

$$\text{I} \cos a = \text{T} \sin a,$$

hence

$$\text{I} = \frac{\text{T} \sin a}{\cos a} = \text{T} \tan a.$$

In the sine-galvanometer, which we shall describe later on, you displace the frame of the multiplier through such an angle that it once more lies parallel to the needle; and therefore so as to make the current act with a force, the direction of which is at right angles to the line of the needle, then the amount of the force that acts on the needle is I, and you have I = T sin a. In this case, the force is proportional to the *sine* of the angles of deviation.

is sufficient then to observe well on the horizontal circle the new positions of equilibrium which the magnetic needle takes under the influence of different currents.

"The source of the electric currents remaining the same, the lengths [and therefore the resistances] of the circuit are changed by introducing successively a series of wires differing only in their lengths; these wires [called 'resistance coils'], covered with silk, are folded up, and covered outside, so as to be preserved always in the same state. Such a series of coils is represented in Fig. 214. The lengths are 5, 10, 40, 70, and 100 metres; you see only the two ends by which these wires are by turns, or simultaneously introduced into the circuit. By this means the same electromotive force acts in circuits of different length, and deviations are found for corresponding strengths of current.

FIG. 214.—A set of separate resistance coils as used by Pouillet.

"The *sine-galvanometer* is represented in Fig. 214; the vertical circle has a groove in which to receive one or many coils of covered wire, through which the current passes; in the centre is a magnetic needle, either suspended or poised on a pivot. There is also a zero mark opposite the middle of the thickness of the circle to show the position of the south pole, but there is a graduated azimuth circle below to determine the angular deviations.

"The vertical circle being in the plane of the magnetic meridian, the needle is at its mark; as soon as the current passes, it is deflected; then you turn the vertical circle to follow the needle and bring to it its mark, so that the plane of the current may always be vertically over the needle.

"When it is stopped in its new position, the graduated circle gives the angle of deviation, which is greater with stronger currents. It is easy to show that the strengths of the current in this case are precisely proportional to the *sines of the* angles of deflexion (see the footnote with Fig. 213). The battery remaining the same, you change the lengths of the circuit by introducing series of wires, as has been described"—(Extract from Pouillet's *Notions générales de Physique.*)

For all delicate work these older instruments are now abandoned. The *Mirror Galvanometer* of Sir William Thomson has become universal wherever a sensitive instrument is required.

Fig. 216 represents the coil, in the centre of which is suspended the magnetised needle. This needle usually consists of three or four very short minute pieces of steel very highly magnetised, fastened behind a small circular silvered mirror : the whole, weighing only a few

FIG. 215.—Pouillet's sine galvanometer.

grains, is suspended by a simple unspun silk thread, and inclosed with the bobbin in a cylindrical case D (Fig. 217).

There are two terminals attached to the ends of the coil for joining it to the ends of the circuit wires. The deflexion of the magnetised needle, occasioned by the passage of the current, is observed in the following way :—

In the shadow of a wooden frame-work there is a horizontal divided scale below the zero of which there is a small hole through which passes a ray of light from a lamp. The ray R passes through the

central opening of the coil of the galvanometer which is placed in front of the box; it strikes upon the mirror of the magnetic needle

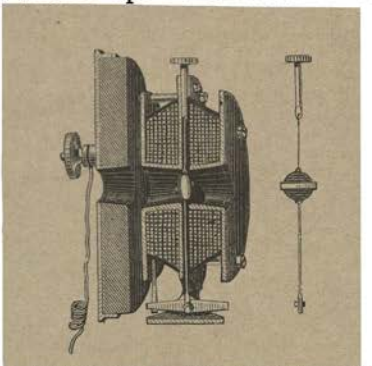

FIG. 216.—Section of Sir W. Thomson's mirror galvanometer.

and is reflected, following the path R′, and when the needle is at rest falls upon the zero of the scale. As soon as the current passes, the needles and the mirror turn; the luminous spot is carried to the right or to the left of the zero, according to the direction of the deflexion; the amplitude of which is read off on these divisions.

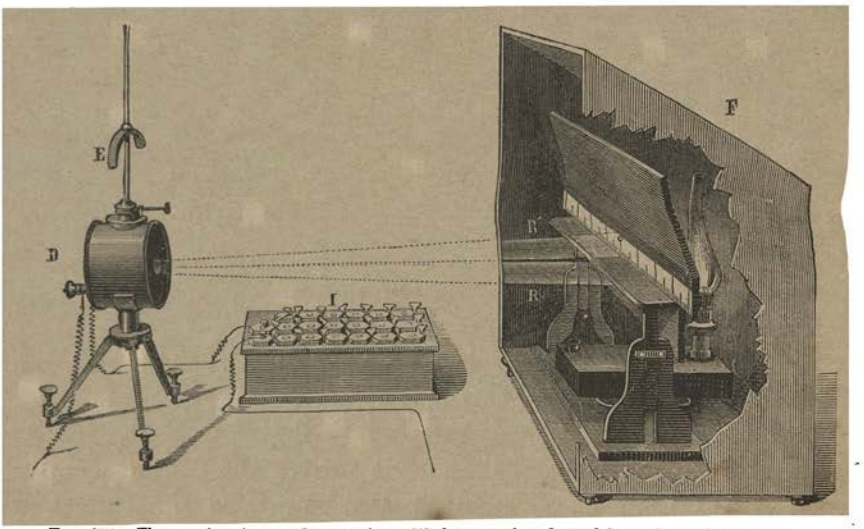

FIG. 217.—Thomson's mirror galvanometer with lamp and scale and box of resistance coils.

Above the coil of Thomson's galvanometer is a vertical rod, bearing a large bent magnet E, feebly magnetised. This magnet fits

loose-tight upon the rod; it can be turned round it and can also slide vertically. The object of this arrangement is to avoid having always to place the apparatus in the magnetic meridian, the bent magnet constituting an artificial magnetic meridian, the directing force of which can be altered at will. For very sensitive work the galvanometer is set in the magnetic meridian, and the controlling magnet is then adjusted so as to compensate almost exactly the magnetic force

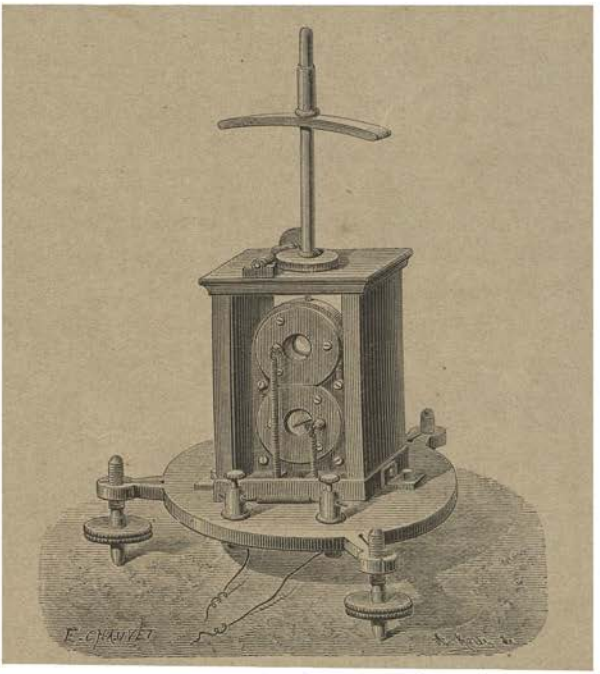

FIG. 218.—Thomson's astatic mirror galvanometer.

of the earth, so making the instrument astatic and excessively sensitive.

Thomson's galvanometers are also constructed with astatic pairs of needles, and are employed with short coils of thick wire, offering very small resistance, and long coils of thin wire having an enormous number of turns. There is in the astatic instruments a coil of wire for each needle, and the current passes in contrary directions in the two coils.

§ 3.—*The Action of Magnets on Currents.*

We have just seen what the action of voltaic currents on the magnetised needle is, and how this influence has been used to construct various instruments,—some of them of excessive sensitiveness,—to measure the strength of currents. Let us now add that magnets exercise forces upon currents equal to that which they themselves experience, but in an opposite direction. Thus, when you place a strongly magnetised bar AB in a horizontal position under or over a metal wire, carrying a voltaic current (Fig. 219), and free to turn around the points of suspension, you immediately see the wire direct itself across the magnet, so that the north pole of the magnet is

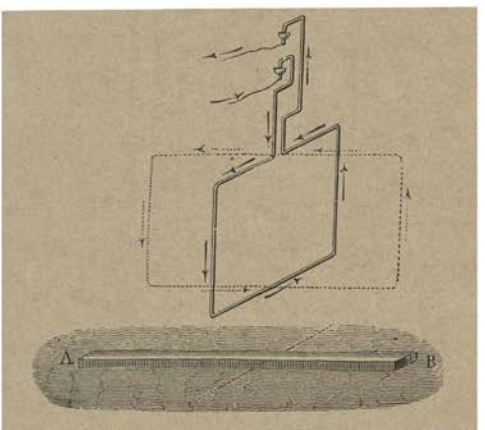

FIG. 219.—Action of magnet on conductor carrying a current.

always on the left of the portion of the current which is the nearest to it. If now the current is reversed in the coil, the wire turns throughly 180°, which again brings its plane into a position perpendicular to the magnetised bar; the north of the latter is then, according to Ampère's definition, still on the left of the current.

So experiment verifies what may be foreseen by relying on the sole principle of equality of action and reaction. There is here the mechanical difficulty of making the conductor which carries the current movable without interrupting its continuity. This Ampère accomplished by means of an ingenious arrangement which he

designed and applied, varying it in innumerable ways in his experiments on the reciprocal actions of currents and magnets.

This arrangement is represented in Fig. 220. Two metal pillars are fixed vertically on a stand, to them are attached the terminals for the battery which furnishes the current. They are surmounted by two horizontal arms bearing at their extremities two cups, x y, each containing a small drop of mercury. The conducting wire bent into a rectangle, or any other form according to the experiments to be made, ends in a double bend, with two points which dip into the cups, so that these points are both at once in a vertical axis above the centre of gravity of the suspended conductor.

The latter is movable; its plane can turn in either direction

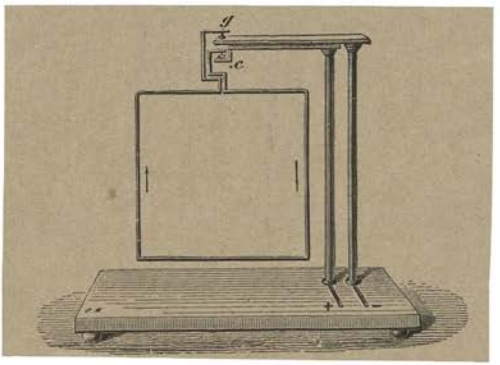

FIG. 220.—Ampère's movable frame for studying electromagnetic phenomena.

round the vertical, and be set in any direction according to the conditions of equilibrium, best suited to the electromagnetic actions that it is desired to study.

This is the arrangement that was used for the experiment we have just described.

Shortly after the discovery of the first electromagnetic phenomena Faraday made an experiment in which the action of a magnet caused a continuous rotation of a current.

A circle of copper (Fig. 221), supported by an arch of copper wire capable of turning freely about a point which rested in a small mercury cup, dipped into some dilute acid contained in a ring-shaped vessel of zinc. The action of the acid on the zinc produced a current which circulated from the copper ring to the zinc through the central

support and the mercury cup. On bringing one pole of a magnet below the zinc plate the copper was found to take up a continuous rotatory motion, the direction of which changed if the pole of the magnet was changed.

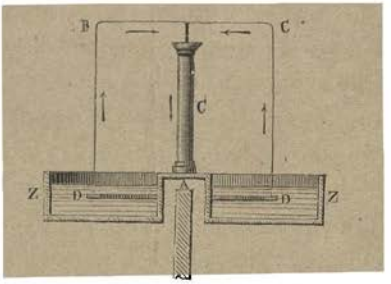

FIG. 221.—Faraday's experiment showing rotation of a current by a magnet.

To Ampère is due the inverse experiment demonstrating the rotation of a magnet under the influence of the current; the Fig. 222 shows how he produced this rotation. In a glass jar filled with mercury he floated a cylindrical steel magnet, maintained vertical by a platinum counterpoise screwed below it. The upper end of the

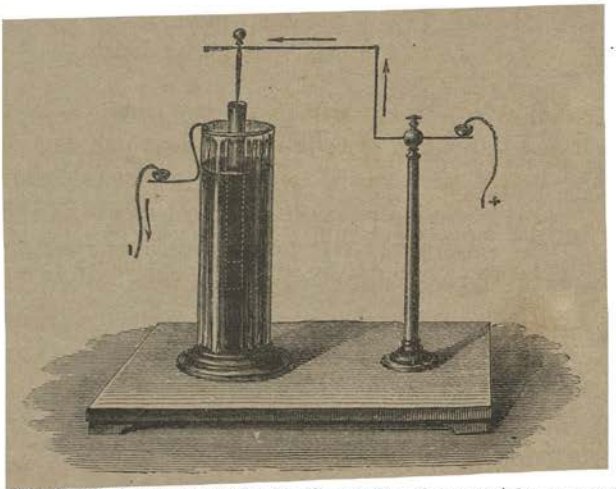

FIG. 222.—Ampère's experiment showing the rotation of a magnet by a current.

magnet was hollowed out like a cup; a little mercury was put into it and into this the point of a vertical conductor dipped in communication with one of the poles of the battery. The other pole was put into connexion by means of a wire with the mercury in the jar. As

soon as the current passed the magnet turned around its axis. The direction of the movement depends on that of the current and changes with it; it depends also on the nature of the pole that is brought into action. When the current enters by the point of the wire, if the pole that is in action at the top is the north pole, rotation takes place in the contrary direction to the hands of a watch, that is to say, from east to west passing by the north.

Faraday, by further modifying the apparatus of Ampère, found the means of producing another kind of rotatory motion. Instead of bringing down the conducting wire into the upper cavity hollowed out in the polar end of the magnet, he dipped it into the surrounding mercury in the glass jar. The magnet pole in this case circulates round the wire instead of turning on itself.

The explanation of these phenomena is easy if once the theory of the constitution of magnets which Ampère laid down is admitted. We shall discuss this theory presently. Meantime we continue to describe the interesting phenomena of the reciprocal influence of currents discovered by this celebrated physicist.

§ 4.—*Action of Currents on Currents.*

When two currents, or two portions of a current, are brought near together you have to consider the direction in which each circulates, the form and extent of the portions of the conductors which act on each other, and the relative position of the elements of the currents considered. Currents may be rectilinear, circular, sinuous, parallel, or oblique; and in the two latter cases two parallel currents or two oblique currents may flow either in the same direction as one another or in contrary directions. Many particular cases thus present themselves. The study of the action of current upon current forms the branch of the science to which the name *Electrodynamics* has been given. The simple laws of this branch Ampère laid down in the following form:—

1. *Two parallel currents*[1] *which flow in the same direction*

[1] [It must be understood in all cases that it is the conductor carrying the current which experiences the forces in question: to be quite precise the expression "conductors carrying currents" should be substituted for the word "currents" throughout this section.—ED.]

attract each other; they repel each other if they flow in opposite directions.

2. *Two currents not parallel attract each other if both converge to, or both diverge from the apex of the angle formed by their directions;*

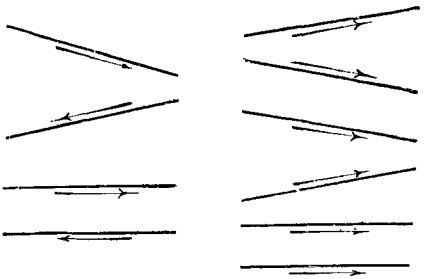

FIG. 223.—Illustrations of laws of attraction of currents on currents.

they repel each other, if one of the currents approaches the apex of the angle, whilst the other recedes from it.

3. *A sinuous current acts on another current in the same way as a rectilinear current, which lies along the same line.*

Fig. 223 represents in the form of a diagram, the three cases of attraction, and the two cases of repulsion mentioned in these laws.

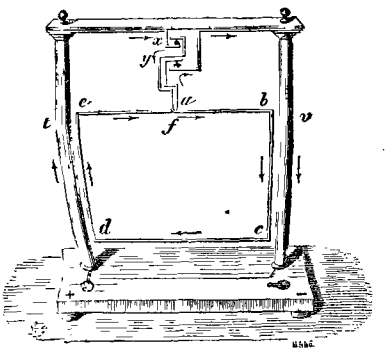

FIG. 224.—Attraction of parallel currents flowing in the same direction.

We will give some examples of the way in which they are verified by experiment.

Fig. 224 shows the arrangement of the apparatus which serves to show the law of action of parallel currents.

Two metal pillars are put into communication with the poles of a battery. The current here rises in the left pillar, and passing under the horizontal bar which unites the tops of the pillars; it enters the rectangular copper wire which forms the part movable round the vertical axis; passing through the two points, and the mercury cups, and traversing all parts in the direction pointed out by the arrows. Here we see that the ascending current in the first pillar *t* is parallel to the current of the vertical side *e d* of the rectangle nearest it. The second pillar *v* and the opposite side near it *b c* of the same rectangle, are in the same way both traversed by two descending parallel currents. Now experiment shows that these parts attract each other. If you separate them from each other by an angular displacement of the movable rectangle, they quickly approach each other, and place themselves so that the plane of the

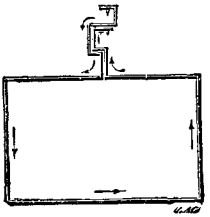

FIG. 225.—Apparatus to show repulsion of parallel currents in opposite directions.

rectangle coincides with that of the pillars. Therefore parallel currents in the same direction attract each other.

If now you substitute for the rectangle, which has been used for this experiment, that of Fig. 225, which is so arranged as to be traversed by the current in an opposite direction, the neighbouring vertical portions of each pillar and the sides of the rectangle, are traversed by currents always parallel, but in contrary directions.

So when you respectively bring them near each other, as soon as the current passes, you find that the rectangle is quickly repelled, and swings round through more than a right angle with the plane of the frame formed by the pillars: in fact it tries to turn right for left.

From this first law of attraction or repulsion of parallel currents, according as their directions are the same or contrary, it follows that two crossing or oblique currents have a tendency to become parallel and concurrent.

The portions of the currents which are both approaching or both receding from the point of crossing, approach or attract each other; those which from this point are flowing in opposite directions tend to separate, repelling each other. These consequences are easily verified, and the laws of currents not parallel are thus demonstrated.

When you consider two consecutive parts of the same current forming a certain angle, they ought, after what we have just seen, to repel each other mutually until the angle becomes 180°, when they become the two consecutive parts in a straight line. Moreover, if two consecutive parallel but non-concurrent portions of a current inclose a space between them, it is found that they are subjected to forces tending to make them move so as to enlarge the area of circuit which they inclose. This fact can be verified also by experiment, in the following way. You take a rectangular wooden trough

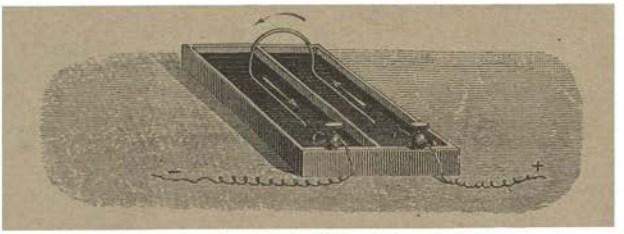

FIG. 226.—Looped circuit tends to enlarge.

divided into two by a partition as Fig. 226 shows, each of them being filled with mercury, and in one is the positive wire, in the other the negative wire from a battery. On the mercury is placed a light metal wire, with two parallel branches connected together by a part of it being bent, so as to put into communication the mercury in the two compartments. This wire completes the circuit, as the arrows of the figure show. Now as soon as the current passes you find that the wire recedes from the points where the battery wires dip into the mercury.

The following is the way in which it is proved that sinuous currents act in the same way as rectilinear currents that lie along the same general path. The two parts of a wire traversed by a current are bent so as to lie close one against the other, but one of these parts is rectilinear, the other is zig-zagged, as Fig. 226 shows. You bring near it one of the sides of the suspended rectangle of

Ampère's movable apparatus. Now you observe no movement, either of attraction or repulsion; it must be then, that the action of the sinuous current, the direction of which is opposed to that of the rectilinear current, is exactly neutralised by the latter.

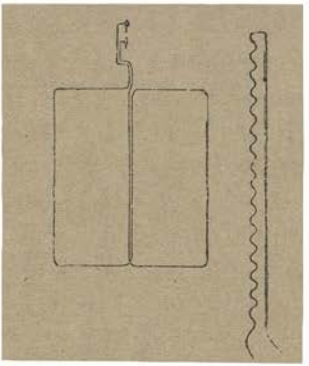

FIG. 227.—Action of sinuous currents.

There is then an equality between these two actions: which proves that the form and mere length of the sinuous part of the current have added nothing to its action.

We will now give an example of a rotatory movement caused by the action of one current on another current.

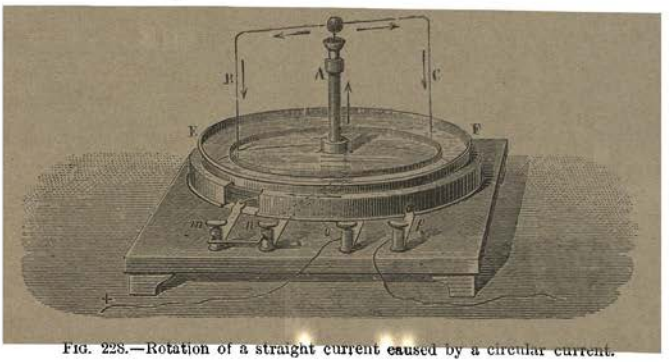

FIG. 228.—Rotation of a straight current caused by a circular current.

The apparatus used for this (Fig. 228) is arranged like the one Faraday employed for the rotation of a current by a magnet. The part B C, movable round the summit of the copper pillar A dips by a circle of copper into the acidulated water of a vessel E F; outside this

vessel is wound a bobbin of wire, one end of which receives the current at O. The other end of the wire is joined to terminals M N and by these to the pillar of the movable instrument. The current then traverses the different sides of this instrument in the direction marked by the arrows; it enters into the acidulated water of the vessel and comes out at P.

As soon as the current passes, you see the movable part of the apparatus turn in a direction contrary to that of the current in the bobbin—the direction marked by an arrow on the edge of the vessel in the figure.

In examining the phenomenon, one readily sees that it is a consequence of the law which regulates the movements of angular currents: one half of the circular current attracts the current of the movable conductor, whilst the other half repels it: these two currents combine to effect its rotation in a direction opposite to that of the circular current.

If you arrange the experiment so that the battery current traverses the bobbin in the same direction, but comes through the acidulated water in the instrument, and descends instead of rising through the central pillar, the movement of rotation, as may be foreseen, is reversed.

§ 5.—*Action of the Earth on Currents.—Ampère's Theory of Magnetism.*

So then, on the one hand, electric currents act on magnets and magnets on currents; and on the other hand, currents act on each other. Hence, to identify magnets with currents, there was only one step; Ampère accomplished it, without once ceasing to call in experiment to control and support his theories. He discovered that the earth itself acts on currents; that if you leave a rectangular instrument like that of Fig. 219 traversed by an electric current to itself, the apparatus turns round its vertical axis, and places itself spontaneously across the magnetic meridian; it is the ascending portion of the current which goes to the west, the descending portion to the east. Pouillet, by the aid of very ingenious arrangements showed that a vertical isolated current, movable round an axis which is

parallel to itself, moves of itself from west to east according as it is ascending or descending, whilst the action of the earth on the horizontal branches of Ampère's apparatus is nil. Seizing these facts Ampère constructed some astatic apparatus, that is to say, apparatus that was indifferent to the action of the terrestrial magnetism. For this, it was necessary to bend the branches of the conductors, so that the terrestrial magnetic action on any one of them should be neutralised by the action on a branch equal, and parallel, and traversed in an opposite direction by the current.

Fig. 229 represents two forms of these astatic conductors. Then making a fixed current act upon them, placed horizontally in a direction perpendicular to the magnetic meridian, from east to west, he saw that the action of this current was precisely the same as the

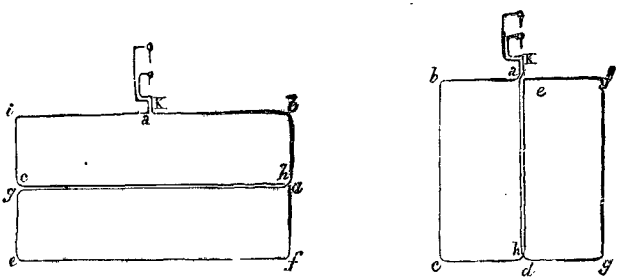

FIG. 229.—Ampère's astatic conductors.

action of the earth. He concluded from this that the magnetic action of the earth on the magnetic needle is due to electric currents which circulate incessantly, below the horizon, at right angles to the magnetic meridian, and the direction of which is from east to west. All these currents, whatever their number, may be considered as composing one single current, and experiment shows that, in our latitudes, its position is situated to the south of us.

Following out these generalisations, Ampère showed that a magnet may be compared to an assemblage of currents, circular, parallel to each other, and flowing in the same direction. Such an assemblage or set of currents being freely suspended, so as to be able to turn in a horizontal plane, subject to the action of the earth will be found to place itself in the magnetic meridian; it will act in the same way as a magnetised needle. Let us see how Ampère realised this

conception by means of the apparatus which we now call a *helix* or *solenoïd*.

He took a metallic wire, and winding it round a cylinder in equidistant coils, he gave it the form shown in Fig. 230, leading back the two ends of the wire longitudinally above the coils, then bending them again so that the whole might freely turn round a vertical axis. This being done, he connected the two ends of the wire to the wires from a battery. When the current passes in the direction marked by the arrows the solenoïd [1] sets itself in a position of stable equilibrium; each coil is in a vertical plane, the direction of which is

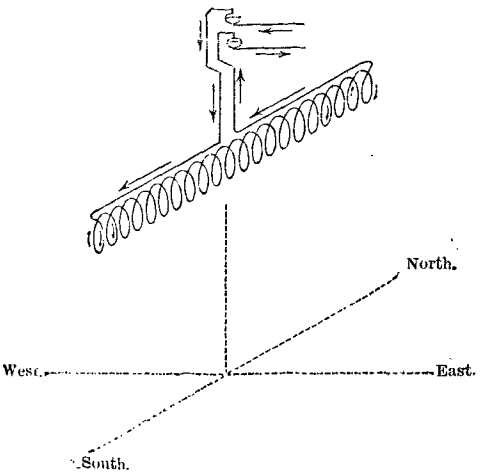

FIG. 230.—Solenoïd setting itself in the magnetic meridian.

magnetically from east to west. The axis of the solenoïd then coincides with the magnetic meridian, just as that of a magnetised needle would. If now you reverse the direction of the current, you will see the solenoïd displaced; and after having turned through 180° it will replace itself in its original position, with its longitudinal axis in the magnetic meridian; but turned end for end. In short a perfectly balanced element of a solenoïd (Fig. 232) suspended so as to be able to turn freely round an axis perpendicular to the magnetic

[1] In a more precise way, the name solenoïd is given to a system of circular currents, arranged so that the axis which passes through the centres of all the circles is perpendicular, or normal to the planes of each of them. This result is obtained in different ways, and Fig. 231 represents several.

meridian, takes an inclination which is precisely equal to that of the magnetic needle: it sets its plane normal to the line of dip. Ordinary

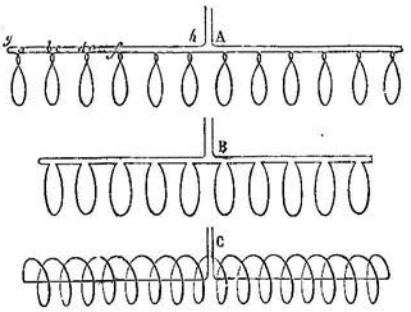

FIG. 231.—Various forms of solenoïds.

magnets then, and solenoïds, or "voltaic magnets," conduct themselves alike under the influence of the magnetic action of the earth.

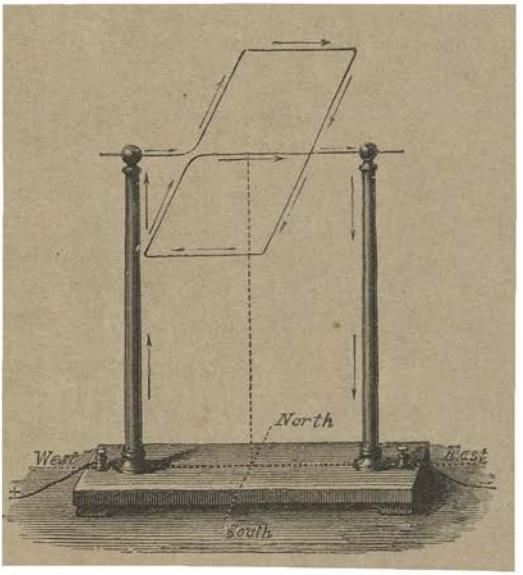

FIG. 232.—An element of a solenoïd, or simple circuit sets itself across the direction of the magnetic dip.

But the analogy has been pushed further. Ampère showed that the extremities or poles of two solenoïds exercise on each other attractions and repulsions of the same nature as the attractions and

repulsions of the poles of magnets: poles of the same name as the solenoïds repel each other; poles of contrary names attract each other. In short the same actions manifest themselves if you present the pole of a solenoïd to either of the poles of a magnet (Fig. 233). The comparison is complete, and Ampère was able to formulate with rigorous completeness his theory of magnetism, a theory which refers all magnetic phenomena to the phenomena of electric currents. The following is a brief account of this beautiful theory:

The terrestrial globe is incessantly traversed by a multitude of electric currents generated by the chemical or other actions which take place within its mass.

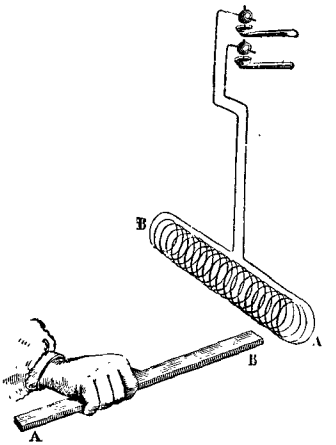

FIG. 233.—Mutual actions of magnets and solenoïds.

All these currents, with directions and strengths probably differing amongst one another, and varying in amount and direction, produce on magnets the same effect as a single resultant current circulating from east to west in a direction contrary to the movement of the rotation of the earth. Every magnetic substance—iron, steel, &c. —is also the seat of elementary electric currents circulating round the molecules or groups of atoms. In soft iron, and in magnetic bodies which are not endued with magnetic polarity, these currents are circulating in miscellaneous directions, so that the resultant effect is zero. In magnets, on the contrary, the molecular currents have all the same cyclical direction; for example, they circulate as the arrows indicate in Fig. 234, where a transverse section of a magne-

tized bar is represented. In the adjoining or contiguous portions in *b b'*, *a a'*, &c., the currents are in contrary directions, and neutralize each other's effects so that the total effect is reduced to the exterior effect, which brings us to consider the contour of each face as being traversed by only one current. The same thing takes place in all the sections, and the magnet will be constituted as Fig. 235 indicates. We see then, according to Ampère's theory, that every magnet may be considered as equivalent to a solenoïd, or better, as being itself a whole one, a bundle of solenoïds or vortices formed by particular currents circulating in planes nearly perpendicular to the line of the poles.

As to magnetic substances such as soft iron, bringing them near to a magnet causes them to temporarily acquire magnetic polarity by the action which the currents of the solenoïd exercise on the currents which are supposed to be circulating round the iron molecules.

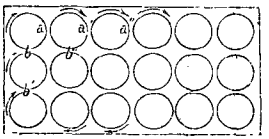

FIG. 284.—Molecular currents in magnets, on Ampère's hypothesis.

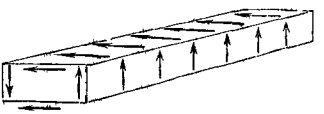

FIG. 285.—Hypothetical currents circulating round a bar magnet.

This influence modifies the directions of these elementary currents, and causes their resultant to be no longer nil; this is the conception, according to Ampère, of magnetisation by induction. We shall see in the following paragraph how Ampère's hypothesis explains permanent magnetism. But in this case it is experiment which must instruct us, in revealing to us phenomena of the highest interest.

Before beginning this latter subject we may note how completely this beautiful hypothesis has revolutionized the older views which regarded magnetism as an isolated science, in spite of the evident analogies between its laws and those of electricity. We now know that the principle underlying magnetic phenomena is electricity itself, associated in some way with a motion round the axis which we call the direction of magnetisation. The contrast between the older

and the newer views has been ably stated by M. Quet in the following paragraphs:

"Before the great discovery of the electro-magnet, in order to explain magnetic phenomena, it was deemed necessary to assume the existence of north and south magnetic fluids; it was further necessary to assume that the homologous particles of these fluids repelled each other in the inverse ratio of the squares of the distances, whilst different particles attracted each other, following the same law. This theory sufficed to explain the magnetic phenomena that were known before the discovery of Oersted, on condition always of his adding two hypotheses.

"It was assumed that the fluids were confined in certain parts of bodies, and that an unknown obstacle prevented them from flowing after the manner of electric fluids. Without this it was impossible to explain why, when a magnet was broken into very small pieces, each particle was a magnet, with its north and south pole.

"It was necessary to suppose that in equal volumes of iron and nickel, the two fluids could not be separated in the same number of corresponding parts; therefore it followed that the two volumes could not have the same magnetic power, as experiment shows.

"When Oersted discovered that the electric current acted on the magnet, the old fluid theory, even with the addition of these two hypotheses, was powerless to explain the new action; and one was obliged to regard the new action as a fundamental fact.

"All difficulties disappeared with the theory of Ampère. Electric currents necessarily keep their places in the particles, and hence each part of a magnet is a complete magnet. The action of particular currents must naturally vary in different bodies, since it depends both on the electromotive force and on the dimensions of the particles; the difference between iron and nickel is then a simple consequence of the theory.

"In short, the action of the magnet on electric currents is, in this theory, an electro-dynamic phenomenon that may be calculated and foreseen, and not an isolated primitive fact.

"This elegant theory of Ampère must then obliterate from science the older hypothesis with its complications of the two useless fluids, the two suppositions made to prop it up; for the older hypothesis failed to explain the new fundamental fact. The theory

which fails when brought to face with the facts is obviously doomed. By the newer theory of Ampère all is made marvellously clear, all is brought to the fundamental fact of the action of currents on each other. In short, the mystery of magnetism is unveiled."

[There is one difficulty about the theory of Ampère which ought not to be passed over in silence. According to this theory every molecule of iron, steel, nickel or cobalt is the seat of a perpetually circulating minute electric current; the theory does not pretend to explain, does not even hint at an explanation, as to the way in which such molecular electric currents have been started, flowing in or around the molecules, or as to the way in which they are maintained. We know that to start a current circulating in any ordinary conductor requires the application of electromotive force, involving the expenditure of energy; and we know also that such currents die out so soon as the electromotive force is removed: they die out because of the resistance in the path of the current which fritters their energy down into heat. Hence one has to suppose that in the first place the molecules of magnetic substances, such as iron, are themselves absolutely perfectly conductive; so that currents once set up *in* a molecule go on circulating for ever round it. As to the origin of such currents we are profoundly ignorant. Those who believe that molecules of iron were created as such will have no difficulty in believing that the currents circulating round them were also created there. Those who hold that iron molecules have resulted from some process of evolution must be prepared to admit that some process of setting up the molecular electric currents has existed. — ED.]

§ 6.—*Magnetism Produced by Currents.*

In September, 1820, a little while after the discoveries of Oersted and Ampère, Arago made the following experiment:—

He plunged into a mass of iron filings a copper wire which was connected to the two poles of a battery; on drawing out the wire, without interrupting the current, he found it to be covered over its whole surface with particles of filings arranged transversely. As

soon as the current was broken the iron particles became detached from the copper and fell down. To assure himself that this was really temporary magnetism, and not the attraction of an electrified body for light bodies, he substituted for the iron filings a non-magnetic substance, such as copper dust or powdered glass, and found that the phenomenon did not take place. On placing needles of soft iron, and then of tempered steel, very near the copper wire and across it, he saw that the action of the current transformed them into magnetic needles, having their south pole always to the left of the

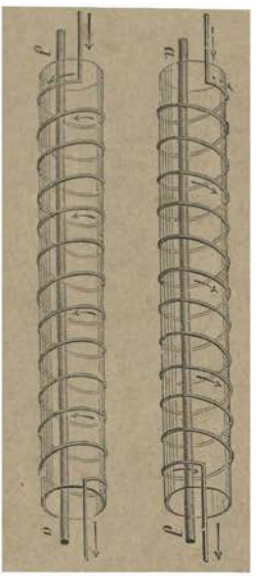

FIG. 236.—Magnetisation of a steel needle by right-handed and left-handed spiral coils.

current, a result in conformity with the earlier experiments of Oersted. Shortly afterwards Arago and Ampère noticed that magnetism of iron or steel is developed much more energetically by placing the needle inside a spiral coil of wire through which the current flows. The wire from a battery is coiled around a glass tube; the needle to be magnetised is then placed in the interior of the tube, and the current is passed. The needle becomes magnetised immediately; but as might be expected, the magnetisation of the iron is temporary, but it is permanent in the case of the steel. As may be seen by Fig. 236, there are two ways of coiling the wire around the tube. Supposing

the tube to be vertical you can coil the wire from top to bottom, each coil passing from right to left on the side of the tube turned towards the operator; this arrangement, *d a*, constitutes a right-handed helix or solenoïd. Or the wire may be coiled so as to pass from left to right, as at *a d*; this is a left-handed helix or solenoïd. If the current traverses the coils of the helix from top to bottom, as the arrows point out, magnetism will give to the needle its north pole at

FIG. 287.—A. M. Ampère.

the bottom of the right-handed helix at the side where the current issues; on the contrary the north pole will be at the top in the needle of the left-handed helix or at the place where the current issues. In both cases, the north pole is always placed at the left of the current, following Ampère's useful law.

By this simple and wonderful method of magnetising, you may

produce intermediate secondary poles at will on the bars which you wish to magnetise; these are called "consequent points," as we have mentioned in our earlier chapter. As Arago was the first to perceive, all that is necessary for producing consequent points is that after having coiled the wire in one direction round the tube for some distance, to coil it in the opposite direction each of the points opposite to the place where the direction of coiling is reversed ought to be a secondary pole. A nondescript helix coiled in this way consisting of a piece wound right-handedly, followed by a piece wound left-handedly, and so forth is shown in Fig. 238.

Steel bar magnets were formerly made by the various methods that we described in the Book on Magnetism, page 39, but at the present time electric currents passing round coils of wire are generally used in preference. The steel bar is placed inside a coil of wire round which a powerful electric current is caused to flow, and

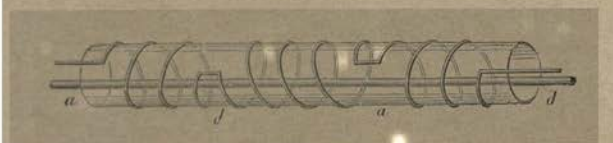

FIG. 238.—Magnetisation by a helix specially constructed to produce consequent poles.

in some cases if the coil is shorter in length than the bar the coil is moved along the bar from end to end several times. The bar will at once become very highly magnetised.

We mentioned in describing the methods of magnetisation one which Elias of Haarlem and Logemann have employed to obtain permanent steel magnets of great power. The following is a description of the process. The steel employed is very highly tempered. When a bar is to be magnetised, a short compact coil of insulated copper wire, having a current circulating in it, is moved several times backward and forward along the bar. When a horse-shoe magnet is to be magnetised a coil is placed on each of the two ends, the current is passed into the two coils, and they are then moved backwards and forwards together over to the two ends of the horse-shoe. A very high degree of magnetic excitation may be attained while using only a single Grove or Bunsen cell, provided the cell has a very low resistance, and that the magnetising coil also has low

resistance, consisting of stout copper wire of a few turns. Elias used a Grove cell the resistance of which was so small as to be equal to that of copper wire of one millimetre in diameter, and two feet in length. His magnetising coil consisted of a wire three millimetres in diameter, and thirty feet in length. The production of powerful permanent magnets has become more important since the invention of magneto-electric machines, and their application to electric light, and electro-plating. De Meritens, the inventor of one of these machines which we shall hereafter describe, magnetises to saturation by a very rapid process the bundles of permanent magnets which are used in his machines. He places two such magnets with their opposite poles together but separated by a thin sheet of copper against which they are fixed. Exciting coils to

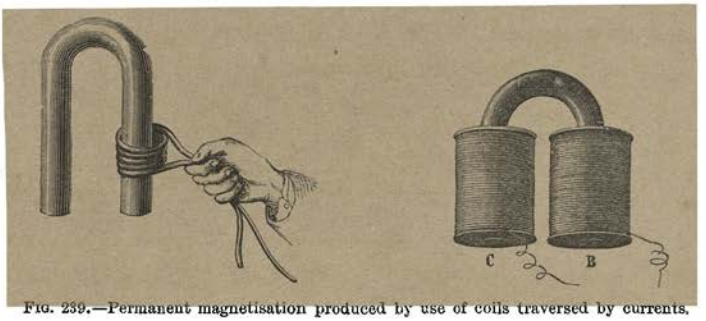

FIG. 239.—Permanent magnetisation produced by use of coils traversed by currents.

magnetise them envelop each bundle; to excite them, he sends through the wire coils the currents of a Gramme machine which he allows to act for twenty seconds, and stops it for twenty other seconds. At each fresh beginning of the current, a violent molecular movement is produced, and the magnetising force is such, that if the apparatus is allowed to work more than ten minutes heat appears at the poles of the magnet. By this means a single assistant is able to magnetise to saturation forty bundles in less than a day. So much for the process of permanent magnetisation.

We have already seen that soft iron surrounded by a magnetising coil takes a temporary magnetisation. The magnetic power thus developed is the stronger as the iron is purer and more homogeneous, and as the number of coils of wire is greater. In order easily to realise this last condition and to use coils of many turns, the metal

wire is coated with an insulating envelope, for example with silk or cotton. A powerful combination is obtained by coiling such insulated wire around a piece of soft iron; the coils being wound on as closely as possible so as to make room for a great number of turns. Such a combination is called an *electro-magnet*, that is to say a magnet the magnetic power of which persists only whilst the flow of the current of the pile continues, and ceases as soon as the current is broken.

Often electro-magnets are made in the form of a horse-shoe; each branch or arm being covered by a coil of the wire (Fig. 240). In this figure the wires appear to be coiled in opposite directions on the two branches; but the direction of the coiling is in reality the same at both ends, as will be seen by imagining the iron core to be straightened out. At the two ends there are, as soon as the current is turned on, two poles of opposite kinds. Electro-magnets are also

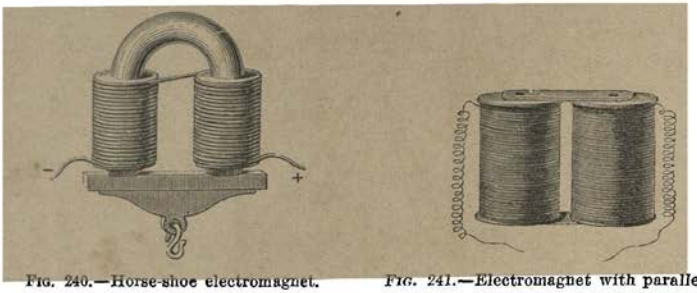

FIG. 240.—Horse-shoe electromagnet. FIG. 241.—Electromagnet with parallel core.

often made with two parallel cores of soft iron, joined on one side by a plate of iron or yoke as shown in Fig. 241. Sometimes the other ends are held together by a brass plate. Other forms, very different from these, are made, according to the use for which they are destined, cylindrical, square, flat, or elliptical.

The first electromagnets were constructed by William Sturgeon, who used a few turns of thick copper wire: the fashion of using many turns of thin wire was introduced by Professor Henry. An electromagnet which Pouillet had constructed for the Faculty of Sciences at Paris, was capable of supporting many thousands of pounds. An electromagnet belonging to Mr. Gordon is formed of a horse-shoe the branches of which are 33 centimètres long, and 63·5 millimètres in diameter; the coils are 30·5 centimètres long, and the diameter outside is 12·7 centimètres; they have

no fewer than 1,000 turns of copper wire of 1·25 millimètres in diameter, and weigh 15 kilogrammes each. Such a magnet placed with the poles downwards and excited by a powerful current would probably bear a weight of about a ton hung to its armature. With such powerful apparatus it is easy to show the magnetic actions exercised on those substances which have hitherto appeared to resist its influence. Independently of the many useful applications which electromagnets receive, and which we shall hereafter describe, they furnish the means of making many curious experiments; for example, that of producing a magnetic chain, by putting under

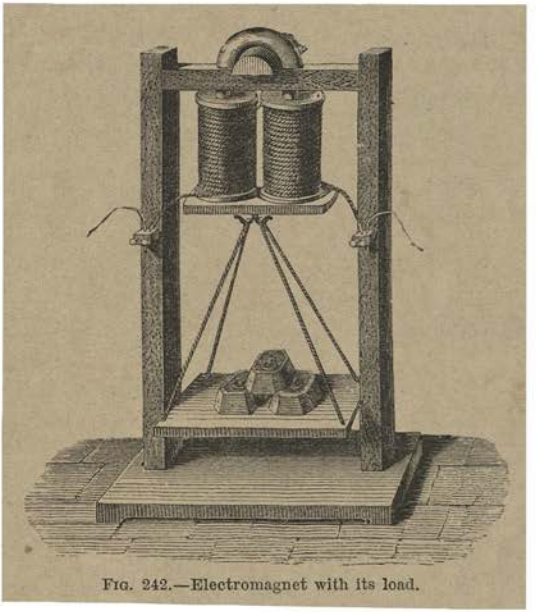

FIG. 242.—Electromagnet with its load.

the poles a mass of magnetic substances, filings, nails, or other small pieces of iron. As soon as the current passes, the little bodies are attracted by the poles, and are magnetised, and hang together by influence as Fig. 243 shows. As soon as the battery circuit is opened, the chain breaks, and all the fragments fall at once.

The promptitude with which soft iron is magnetised, when the electric currents are turned on, and demagnetised when the current is turned off, has given rise to many important applications of electromagnetism; foremost of which is the construction of electro-

magnetic engines in which the moving power is electricity, and which are much more convenient for many purposes, than steam-engines or gas-engines, particularly for light work. But it is above all in electric telegraphy that the electromagnet plays its chief part; here emphatically the theoretical speculations of the most abstract order touch the practical applications of the highest social and commercial utility. Later on we will render justice to the inventors of the

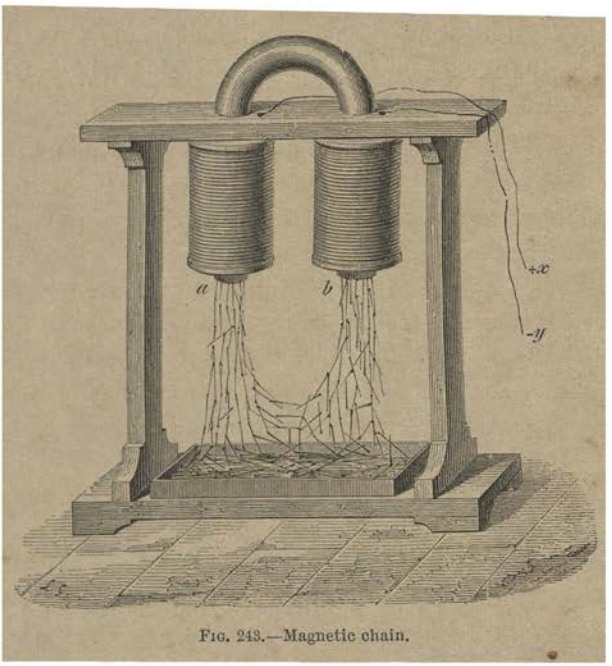

FIG. 243.—Magnetic chain.

systems which have realised this method of communication, which is as instantaneous as thought. For the moment we content ourselves with pointing out to the gratitude of the civilised world the names of Volta, Ampère, Arago, and Sturgeon. It is to these illustrious men that we owe the discovery of principles which are the foundation of this wonderful invention.

§ 7.—*Diamagnetism.*

In describing the general phenomena of magnetism, we have seen that a small number of substances, such as iron, nickel, and cobalt, possess the property of being attracted by the magnet; some of these substances can also acquire in a permanent way magnetic polarity; that is to say can become themselves magnets. In the old theory of two fluids, it was necessary to believe in the existence, so to speak, of a privileged class of substances. But, since magnetism and electricity have been shown to possess so direct a connection to a common cause,—as is clearly proved by the many phenomena of the mutual action between magnets and currents,—it has become difficult to recognise any radical distinction between magnetic and non-magnetic bodies.

If, as the theory of Ampère requires, the particles of magnetic bodies must be considered as being small closed circuits in which electric currents perpetually circulate, and if the action of a magnet or a magnetising coil consists simply in directing or turning into position these particular currents, it might be asked why so many bodies are deprived of this property. In fact this question has been asked, and experiments made from this point of view have resulted in the discovery that magnets have an action upon bodies in general, whether they belong to the class specifically called magnetic bodies, or not. But to perform these experiments it is necessary to use magnets of great power, such as the powerful large electromagnets, which we have just described.

During the last century, and the first half of this, many researches were made, which showed that magnets exercised an action upon various substances till then considered non-magnetic. Coulomb caused fine needles of gold, silver, glass, wax, &c., to oscillate in his balance: but his own experiments, and those of Biot, caused him to think that the action of the magnet may in these circumstances be attributed to particles of iron, too small to be detected by chemical analysis. Anyhow, one great fact, already partially examined by Brugmans, was established in 1828 by Lebaillif: namely, that the metal bismuth, and also the metal antimony, exercise a repulsion on the magnetised needle.

It was impossible to explain this anomaly by the presence of iron or any other magnetic substance in the two metals.

To Faraday belongs the honour of having shown that the magnetic property is general; or at least that almost every substance, solid, liquid, or gaseous, yields to the influence of the magnet. Only the action is attractive for some, repellent for others; so that bodies may be divided into two distinct classes, the first including substances which like soft iron, are attracted by the poles of a magnet; the second, substances which, like bismuth, are repelled by them. Faraday calls the first *paramagnetic* (or simply magnetic); the others are called *diamagnetic* substances.

Let us go on to the experiments which served to demonstrate these new properties.

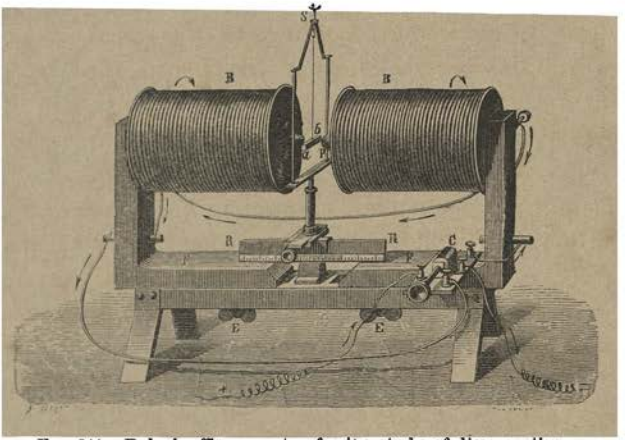

FIG. 244.—Ruhmkorff's apparatus for the study of diamagnetism.

Ruhmkorff constructed for the study of magnetism a special form of electromagnet, of great power, arranged as Fig. 244 shows. The two coils have their iron cores united by means of two L-shaped pieces of soft iron, which can slide horizontally over a stout iron yoke, so allowing the poles to be placed at any convenient distance apart; two clamping-screws, EE, keep them in position. The axes of the coils and the opposing poles of the electromagnet lie on the same horizontal line. The pole-pieces P. sometimes have the form of rounded lumps or blunted cones, sometimes of plane surfaces. They may be screwed to the inner ends of the cores of the two bobbins.

In order to study a solid substance it is cut into the form of an

elongated bar *a b*, which we suspend horizontally by means of a support S above the middle of the line joining two poles. Then the current is passed. If the body on which we are experimenting is magnetic, it turns about its point of suspension till its axis coincides exactly with the axial line of the poles of the electromagnet; if we use a torsionless thread, the bar settles in this *axial* position. If on the contrary the body on which we are experimenting is diamagnetic, we shall find the bar place itself perpendicular to the line of the poles, and take the position which Faraday called *equatorial*.

In the first case, under the influence of the electromagnet, the bar has become a temporary magnet, with two poles, which are attracted to the two opposite polar surfaces; in the second case the bar being diamagnetic is repelled by both the poles of the electromagnet. The two classes of paramagnetic or diamagnetic substances are therefore distinguished according to the axial or equatorial direction which the bars take when freely suspended between the poles of a powerful electromagnet.

"With this apparatus," says M. Quet, "there is no solid body which does not show itself either magnetic or diamagnetic. Among the metals, iron, nickel, cobalt, manganese, chromium, cerium, titanium, palladium, platinum, and osmium, are magnetic; whilst bismuth, antimony zinc, tin, cadmium, sodium, mercury, lead, silver, copper, and gold, are diamagnetic. It is to be remarked that crown glass is magnetic, and flint glass diamagnetic, that organic substances are mostly diamagnetic; lastly, that vermilion, red-lead, peroxide of lead, asbestos, and paper, are magnetic, and that the crystals of the yellow and red ferrocyanides of potassium are diamagnetic."

So much for solids. Liquids are also influenced by the electromagnet, and are divisible into two classes according as they are attracted or repelled. To observe these properties Faraday inclosed liquids in a small and very thin glass tube, which he suspended horizontally between the poles of the electromagnet, and which took the axial or equatorial direction according as the liquid was magnetic or diamagnetic. Plücker put the liquid into a watch-glass placed on suitably-shaped pole pieces: the liquid lengthened itself in the axial direction, and became shallow in the middle if it were magnetic; on the contrary, it became convex according to the equatorial direction, if it were diamagnetic. Quet used for the same study a glass tube

placed horizontally between the two poles of the electromagnet, in a direction perpendicular to the line of the poles. "A drop of liquid," he says, "is put into the tube, and its middle is placed on the right or the left of the same line. As soon as the electromagnet is excited the drop is repelled in the tube, and the repulsion remains permanent, if the liquid is diamagnetic; it would be attracted and its middle would be placed on the line of the poles if the liquid were magnetic. It has been ascertained by these different methods that water, alcohol, ether, and the greater part of organic liquids are diamagnetic. No body, solid or liquid, remains indifferent when the electromagnet is powerful enough, unless it is a mixture, in suitable proportions, of

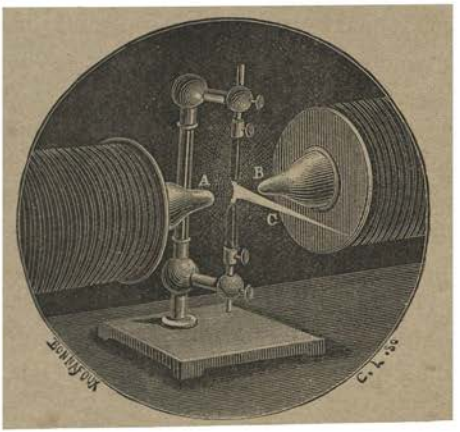

FIG. 245.—The voltaic arc repelled out of the magnetic field.

magnetic with diamagnetic liquids." Blood is diamagnetic, although it contains iron, gases also yield to the influence of magnets. The flame of a lamp, the smoke of that same flame, the vapours of water and alcohol placed between the poles of the electromagnet, all show a repellent action. Sir Humphrey Davy discovered that the magnet exercises a repellent action on the voltaic arc. The experiment may be tried as Fig. 245 shows. The electrodes of carbon between which the light of the luminous arc plays are placed between the ends A and B of the conical pole-pieces of the electromagnet. As soon as the magnetism of the latter is excited by the current, the arc becomes longer, and streams out sideways in the equatorial direction almost like a blow-pipe flame, and to a distance ten times as

great as that of the original arc. A hissing noise is heard, then a loud snap, if the force exerted by the magnetic field is strong enough to break the arc. We shall see later other interesting effects of magnetic action on electric discharges of different forms. [This repulsion of the voltaic arc is not strictly a diamagnetic phenomenon; it should properly be classed with other cases of the force exercised by a magnetic field upon a conductor which carries a current. Possibly the action of the magnetic field on flames belongs to the same category.]

The paramagnetic and diamagnetic powers vary considerably between one substance and another. Faraday studied these powers in the metals, and from his experiments he deduced the following list, which comprehends on one side the magnetic metals, and on the other the diamagnetic metals, arranged in the order of their decreasing power, beginning with iron and bismuth; the metals having the feeblest magnetic or diamagnetic power are nearest the neutral point or zero. But it must not be forgotten that the magnetism of iron is much more intense than the diamagnetism of bismuth: the strength of the pole of an electro-magnet with a core of iron is, according to Thalen, from 32 to 45 times numerically greater than the number of units of the magnetising force; that of a core of bismuth would only be the 400,000th part. Hence the magnetic power of iron is from 13 to 18 million times as great as the diamagnetic power of bismuth.

LIST OF METALS.

Magnetic.	*Diamagnetic.*
Iron.	Bismuth.
Nickel.	Antimony.
Cobalt.	Zinc.
[Manganese].	Cadmium.
Chromium.	Sodium.
Cerium.	Mercury.
Titanium.	Lead.
Palladium.	Silver.
[Platinum].	Copper.
Osmium.	Gold.
	Arsenic.
	Uranium.
	Rhodium.
	Iridium.
	Tungsten.

[It is now generally considered that pure manganese and pure platinum are non-magnetic.]

Edmond Becquerel has proved that the attraction exercised by the poles of an electromagnet on a centimetre cube of oxygen at normal pressure is about the fifth of the repulsion that a centimetre cube of water undergoes in the same conditions; it is equal to 0·18 or 0·187, according as the water is in the air or in a vacuum. If you reckon up the actual quantity of matter present, you will find that the magnetic power of oxygen is 126 times stronger than the diamagnetic power of water. The magnetism of oxygen, which is the only magnetic gas known, decreases with its density, when, the temperature remaining the same, the pressure is diminished. It becomes much weaker when the temperature rises. Air is five times less magnetic than oxygen, whence it is evident that its magnetism is due to the oxygen which it contains.

The magnetic power of oxygen made Faraday imagine that it must be concerned in the phenomena of terrestrial magnetism.

It is interesting to learn the views and the researches of the illustrious English philosopher on this subject. "Oxygen," says Faraday himself (*Experimental Researches in Electricity*, vol. iii. p. 198), "cannot exist in the atmosphere, exerting such a remarkable and high amount of magnetic force, without having a most important influence on the disposition of the magnetism of the earth as a planet; especially if it be remembered that its magnetic condition is greatly altered by variations in its density and by variations in its temperature. I think I see here the real cause of many of the variations of that force, which have been, and are now, so carefully watched on different parts of the surface of the globe. The daily variation and the annual variation, both seem likely to come under it; also very many of the irregular continual variations, which the photographic process of record renders so beautifully manifest. If such expectations be confirmed, and the atmosphere be found able to produce results like these, then we shall probably find a new relation between the aurora borealis and the magnetism of the earth; namely, a relation established, more or less, through the air itself in connection with the space above it; and even magnetic relations and variations which are not as yet suspected may be suggested and rendered manifest and measurable in the

further development of what I will venture to call *Atmospheric Magnetism.*"

Faraday devoted to the study of this interesting question two memoirs, in which he discussed the effects of heat and cold on the magnetism of the air, and the action of the magnetised needle which ought to result on the changes of the temperature; he applied the results of his researches in explanation of the annual, diurnal, and irregular variations of terrestrial magnetism, which were described in a preceding chapter. Since Faraday's time other causes have been suggested, notably cosmic causes, such as the periodical appearance of sun-spots; but it does not seem to us that these necessarily exclude the cause suggested by Faraday. It is at least conceivable that the magnetic action of the sun is primarily exercised on the atmosphere or on the oxygen, which is so important a constituent of it.

§ 8.—*Action of Magnetism on Polarized Light.*

The first works of Faraday on diamagnetism were founded on an interesting discovery, on which we shall say a few words here. It relates to the action of magnetism upon polarized light. This is how he describes the experiment which revealed to him this property. Having succeeded in producing, in order to perfect the quality of glass employed in optics, a heavy glass and one of great refracting power (silico-borate of lead), he made use of it in the following way:—

"A piece of this glass about two inches square and 0·5 of an inch thick, having flat and polished edges, was placed as a diamagnetic between the poles (not as yet magnetized by the electric current), so that the polarized ray should pass through its length; the glass acted as air, water, or any other indifferent substance would do; and if the eye-piece were previously turned into such a position that the polarized ray was extinguished, or rather the image produced by it rendered invisible, then the introduction of this glass made no alteration in that respect. In this state of circumstance the force of the electromagnet was developed by sending an electric current through its coils, and immediately the image of the lamp-flame continued magnetic. On stopping the electric current, and so causing

the magnetic force to cease, the light instantly disappeared; these phenomena could be renewed at pleasure, at any instant of time and upon any occasion, showing a perfect dependence of cause and effect"[1] (*Experimental Researches*, vol. iii. section 2154).

These experiments were extended to many singly-refracting bodies, which all acquired rotatory power under the influence of magnetism, though crystals endowed with double refraction were found to be but little sensible under it. A new chapter was in this way added to physical optics, as well as to magnetism and electricity.

The laws of this rotatory movement of polarized light under the action of magnets have been studied by Faraday and many other philosophers, among whom we will mention Verdet. To set them forth here would be beyond our aims, and we would direct the reader desirous of instructing himself in these matters to the study of the special memoirs on the subject. We will limit ourselves to saying that the direction in which rotation is impressed is, in many substances, in the same sense as that of the electric or electromagnetic currents; nevertheless Verdet has shown that the rotation impressed is in the opposite sense in transparent substances composed of iron, titanium, and cerium; whilst it is sometimes direct, sometimes inverse, in compounds of manganese. When the luminous ray, which is supposed always to penetrate normally through the bar of glass, is parallel to the line of the poles, the angle of rotation is greatest; it decreases as its direction varies from this parallelism, to become nil in the perpendicular direction. In all this the magnetic intensity is supposed to remain unchanged; if it vary, the angle of rotation, all else being the same, varies in proportion.

The theoretical importance of these phenomena will not escape any one. It was from theoretical views that Faraday was led to this brilliant discovery of the magnetic power of magnets on light. It would be appropriate to finish this paragraph by quoting the following fragment of his general conclusions in order properly to determine the whole compass of it: "Thus is established, I think for the first

[1] Instead of employing an electromagnet (which was here excited by five Grove's cells, and each pole of which would carry up to 26 kilograms), Faraday afterward reproduced the same experiment with a good permanent steel horse-shoe magnet. The results were more feeble, but sufficient to show the identity in action on light of ordinary magnets with electromagnets.

time, a true direct relation and dependence between light and the magnetic and electric forces; and thus a great addition made to the facts and considerations which tend to prove that all natural forces are tied together and have one common origin. It is no doubt difficult, in the present state of our knowledge, to express our expectation in exact terms; and though I have said that another of the powers of nature is, in these experiments, directly related to the rest, I ought perhaps rather to say that another form of the great power is distinctly and directly related to the other forms; or that the great power manifested by particular phenomena in particular forms is here further identified and recognized by the direct relation of its form of light to its forms of electricity and magnetism" (*Experimental Researches*, vol. iii. art. 2221).

[It would hardly be right to close this chapter without adding a reference to the developments which recent years have brought to this the most transcendent discovery of the nineteenth century—the relation between magnetism and light. Dr. Kerr of Glasgow has shown that the plane of polarisation of light is also rotated when it is reflected from the polished end of a magnet or electro-magnet; and Kundt of Strasburg has shown that transmission of polarised light through a magnetised thin transparent film of iron produces the same effect. Further, Dr. Kerr has shown a direct relation to exist between an electric charge and the rays of light; for he found that when a piece of glass is placed between the discharging poles of an electric apparatus (induction coil, influence machine, &c.), and subjected to a severe electrostatic stress, it is able to modify a transmitted beam of polarised light. Again, Willoughby Smith discovered the singular fact that the metal selenium is a better conductor of electricity in light than in the dark; a property applied in the *Photophone* of Graham Bell and Tainter.

But most important of all the deductions from Faraday's fundamental discovery is the startling doctrine, enunciated by the late lamented Clerk-Maxwell under the name of the *Electromagnetic Theory of Light*, that light itself is simply an electromagnetic phenomenon; that what we call waves of light are not mechanical waves at all, but are immensely rapid electric displacements taking place in the all-pervading "ether of space," and accompanied (as all electric movements are) by magnetic forces in directions at right-

angles to the electric displacements. According to this theory (which therefore reconciles the conflicting theories about the direction of the vibrations in polarised light), both the electric and magnetic motions are executed in planes at right-angles to the line of propagation or ray. It is believed by the editor of this work that this theory, which is now in the main accepted by all the younger generation of physicists, will be able, with proper modifications and developments, to explain the curious relations existing between electricity and the phosphorescent, fluorescent, and chemical properties of light. It has further led the editor to the conclusion, to which other lines of argument now appear to be converging, that the "ether" in which light is propagated, and which in all probability is the medium through which also all electric and magnetic forces are propagated when they act apparently "at a distance," is nothing else than *electricity* itself.—EDITOR.]

CHAPTER IX.

INDUCTION.

§ 1.—*Phenomena of Induction by Currents.*

THE name of Faraday again presents itself in the discovery of the new and remarkable phenomena, which were first made known fifty years ago, and which we shall describe in the present chapter.

Faraday, in the month of November, 1831, made the curious observation that at the moment when an electric current was made to pass along a wire, there was produced in a neighbouring wire lying parallel to the first, but completely separated from it by an insulating body, a second momentary current opposite in direction to the first current. The existence of the current thus developed or induced in a wire by the influence of the current in a neighbouring one is detected by putting a galvanometer into each of the separate circuits; and it is found that at the very same instant that the needle of the galvanometer in the first circuit moves, the needle of the second galvanometer shows a sudden impulse. The needle of the second galvanometer is, however, observed to come back to zero although the first current continues to circulate in the first circuit. But if now the first current is stopped, another momentary current is produced in the neighbouring wire, parallel this time in an inverse direction, and it also ceases immediately. To the primitive current is given the name of the *inducing current* or *primary current;* to the current produced in the neighbouring wire when the primary current is turned on, the name of the *inverse induced current* or *inverse secondary current* is given; lastly, to the current which is developed

in the neighbouring wire when the primary current is broken, the name of the *direct induced* or *direct secondary current* is given.[1]

Magnets produce induced currents just as voltaic currents do. So also, as Masson proved in 1834, do discharges of static electricity. We will rapidly pass in review the principal experiments in this new series of phenomena, after which we will describe some apparatus which gives extraordinary discharges and sparks.

To obtain tolerably intense induced currents, it is necessary to employ parallel wires of considerable length. For convenience the two wires, instead of being laid straight out, are coiled up on a bobbin, each of the wires having been previously over-spun with silk or cotton varnished. Or we may employ two such bobbins or coils, each wound with one long wire. It is usual to bring out the ends of the wire to a pair of brass terminal screws on the base board or end of the bobbin, to serve to connect the coiled wire either with the two terminals of a battery or with a galvanometer.

Suppose we select two bobbins, one of bigger diameter than the

[1] It is interesting to see how Faraday arrived at the discovery of induction, which, had the principle of conservation of energy been known at that time, might have been predicted as a mathematical consequence of the discoveries of Ampère made ten years previously. This is how Tyndall relates this most striking of Faraday's investigations :

"He began his experiments on the induction of electric currents by composing a helix of two insulated wires, which were wound side by side round the same wooden cylinder. One of these wires he connected with a voltaic battery of ten cells, and the other with a sensitive galvanometer. But he never accepted an experimental result until he had applied to it the utmost power at his command. He raised his battery from 10 cells to 120 cells, but without avail. The current flowed calmly through the battery wire without producing, during its flow, any sensible result upon the galvanometer.

"'During its flow,' and this was the time when an effect was expected—but here Faraday's power of lateral vision, separating, as it were, from the line of expectation, came into play—he noticed that a feeble movement of the needle always occurred at the moment when he made contact with the battery; that the needle would afterwards return to its former position and remain quietly there unaffected by the *flowing* current. At the moment, however, when the circuit was interrupted, the needle again moved, and in a direction opposed to that observed on the completion of the circuit. This result, and others of a similar kind, led him to the conclusion 'that the battery current through the one wire did in reality induce a similar current through the other; but that it continued for an instant only, and partook more of the nature of an electric wave from a common Leyden jar than of the current from a voltaic battery'" (*Faraday as a Discoverer*, p. 24).

other, so that the smaller one may be put into the hollow of the bigger one. Let the latter be put into communication with a galvanometer, so that it may be used as induced (or secondary) bobbin; the inner coil may then be used as the inducing or primary bobbin, and it should be included along with a key, in the circuit of a sufficiently powerful battery such as a Bunsen cell. As soon as the primary circuit is closed, the needle of the galvanometer in the secondary circuit may be seen to indicate by its deflection that an inverse induced current, lasting only for an instant, has been set up in the coils of the outer bobbin at the moment when the current was turned on in the inner bobbin: for it will be seen that the needle immediately comes back to zero (after some oscillations), and it remains at zero as long as the current in the primary bobbin goes flowing steadily on.

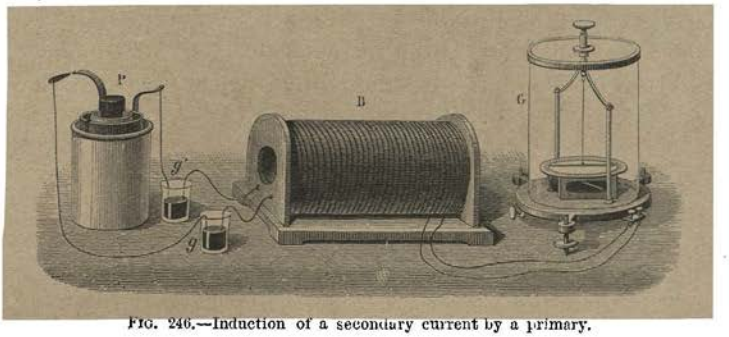

FIG. 246.—Induction of a secondary current by a primary.

Suppose now, by moving the key, the exciting current is broken, the needle is deflected in another direction, indicating thereby the presence of a direct induced current in the secondary coil. Then it comes back to zero again, and remains there as long as the primary current is broken.

What does this first experiment show? That every voltaic current, at the instant that it begins, develops in a neighbouring conducting wire an inverse current; at the moment when it finishes, a direct current. It also shows that this inductive action is due to *a change* in the strength of the neighbouring current, and depends not on its strength, but on changes in its strength.

Fig. 246 shows an apparatus for demonstrating this. The primary circuit in this case includes the Bunsen cell, P, on the left and the

inner bobbin of the induction coil that stands in the middle; in this case the connections of the primary circuit are made, not by screws, but by mercury cups, *g*, *g*. The secondary coil—in this case the outer one—is joined to the galvanometer on the right. When the wires are dipped into the mercury cups, the galvanometer needle shows a sudden movement in one direction; if either wire be pulled out of the mercury cup, the needle shows a movement in the other direction, proving that the currents induced respectively on opening and on closing the primary circuit are of opposite signs.

Now suppose that the primary bobbin is taken out from the secondary, and that while the coils are thus apart it is connected to the battery and the circuit closed, as Fig. 247 shows us. Suppose

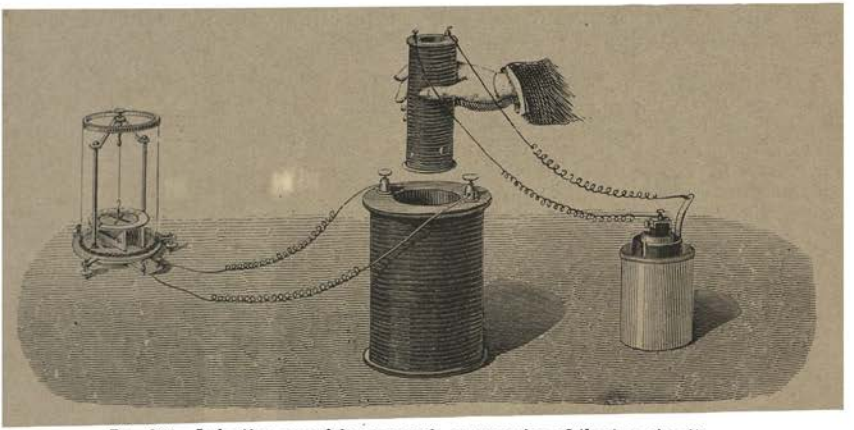

FIG. 247.—Induction caused by approach or recession of the two circuits.

also that the secondary bobbin is joined up to the galvanometer. If then the primary bobbin is quickly brought near the secondary bobbin, an inverse current is found to be indicated by the deflection of the needle of the galvanometer. This current immediately ceases; but if you then move away the primary bobbin a direct induced current is developed in the secondary, but it also ceases immediately like the first. In short, bringing up the primary circuit has the same effect on the secondary as starting the current in the primary had in the former experiment, whilst recession of the primary has the same effect as the dying out of the current produced.

Suppose that we now try over again the two preceding experiments, but that, after having turned on the current and got

our first deflexion, we suddenly increase the strength of the primary current, what will happen? At the instant when this increase takes place, the needle of the galvanometer, which had come to zero, will again indicate the presence of an inverse secondary current.

To realize this experiment we must connect two intermediate points by a *shunt*. A shunt is the name given by telegraph engineers to a by-pass line or wire connecting two points of a circuit. By Continental electricians a shunt wire is called a *derived circuit* or a derivation.

Fig. 248 shows the two mercury cups connected by the shunt *d*. Suppose that the shunt is first placed across the mercury cups; then the wires of the primary coil put in position; then, lastly, the wires

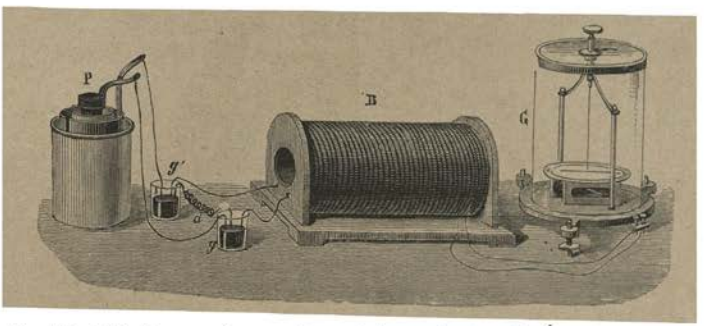

FIG. 248.—Induction currents caused by variation in the strength of a primary current.

from the battery-cell. The current which then starts will not all flow through the primary coil; for some of it, perhaps more than half, will flow by the by-pass circuit or shunt. The current through the primary coil will therefore be a weak one; nevertheless, at the instant when the battery is joined up, a weak momentary inverse secondary current may be detected by the galvanometer. Let this first deflexion subside, the primary current flowing all the time. Then suddenly remove the shunt wire: the whole of the current of the battery will now have to flow round the primary coil, as there is no longer any by-pass route. The primary current in the coil suddenly grows stronger, and at the same instant the galvanometer in the secondary wire will show another momentary inverse induced current If by replacing the shunt the current is then weakened it will be found that there is excited a momentary direct secondary current.

We may then sum up in the following way the phenomena of induction by a current :—

A voltaic current develops by induction in a neighbouring wire a current in the opposite direction to its own, that is to say, an inverse induced current, every time—

1. That it begins;
2. That it is brought near;
3. That its strength is increased.

The same current produces a direct induced current, or in the same direction as its own, every time—

1. That it ceases;
2. That it is moved further away;
3. That its strength is diminished.

The same phenomena can, as we shall see, be produced with magnets as with electric currents; and the ingenious theory of Ampère thus receives from the experiments of Faraday a new confirmation.

§ 2.—*Induction by Magnets.*

Let us take a hollow bobbin coiled with insulated wire, having its ends connected up with a suitable and sensitive galvanometer. Let us place a magnet in the axis of the cylinder, and quickly bring one of its poles near to, or actually into, the bobbin; the needle of the galvanometer is immediately deflected, and then returns to zero. In making this experiment care should be taken to have long wires from the bobbin to the galvanometer, so that the latter may be far away from the bar magnet and not directly affected by its presence. The direction of the deflection indicates that a current has been made to circulate around the coil in a direction opposite to that which, according to the theory of Ampère, represents the action of the magnet pole that has been employed. The induced current ceases immediately, and nothing more is seen whilst the magnet remains at rest in position. If you quickly take it away, the needle of the galvanometer is deflected in a contrary direction, and then after some oscillations returns to zero.

The contrary direction proved that the induced current was a direct one. Before bringing the magnet near, let us suppose that you have introduced into the bobbin a core of soft iron (Fig. 250). If

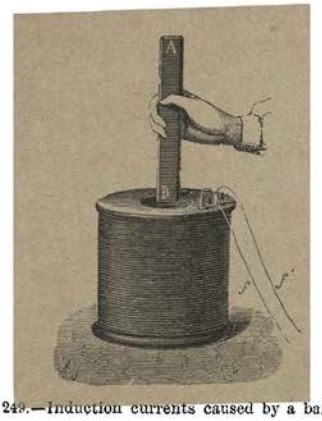

FIG. 249.—Induction currents caused by a bar magnet.

now you bring near one of the poles of the magnet, an inductive action will take place resulting in the production of an inverse current, and this will be found to be much more powerful than was the case without an iron core, for in the present experiment the

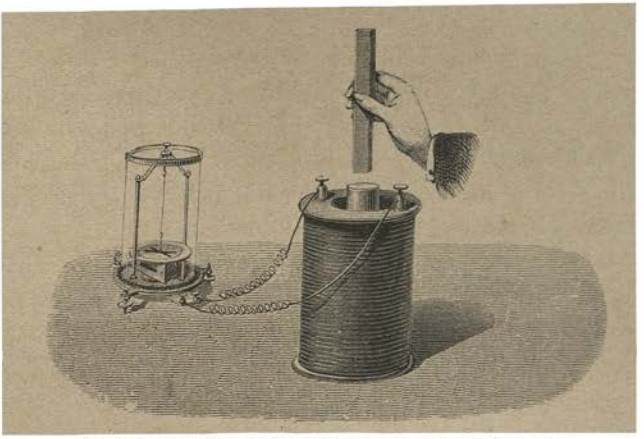

FIG. 250.—Induction assisted by presence of a soft iron core.

needle of the galvanometer is observed to make larger and more sudden movements. The same remark applies to the direct induced current, which the rapid removing of the magnet develops in the

bobbin. If you use the other pole of the magnet all the deflections are reversed, proving that the currents induced in the secondary circuits by the inductive influence of south poles run round in the opposite way to those induced by north poles.

To sum up, induction is exerted on a conducting wire by a magnet, accompanied by the production of an inverse induced current, every time:

1. That the magnet pole approaches.
2. That its magnetism is established.
3. That the strength of its magnetism is increased.

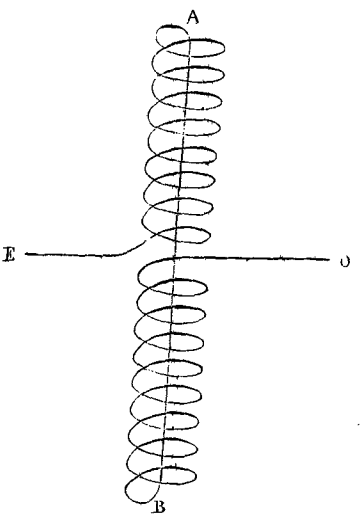

FIG. 251.—Inductive action of the earth.

There is, on the contrary, a production of a direct induced current:

1. If the magnetic pole is removed.
2. If its magnetism is destroyed.
3. If its magnetism is diminished.

The earth being a gigantic magnet, it ought like other magnets to be susceptible of producing currents by induction.

This is indeed what does take place; and the experiments of Faraday have again proved the point. Taking a coil A B Fig. 251,

the ends of which E and O form an axis round which the system can turn, he placed this axis horizontally in a direction perpendicular to the plane of the magnetic meridian, and gave to the coil a position parallel to the dipping needle.

Then he gave to it a brisk movement of rotation round E O; a galvanometer communicating with the wires of the coil indicated the instantaneous appearance of a current, the direction of which changed at each half revolution. Faraday at first placed in the coil a bar of soft iron, which became magnetised under the influence of the earth, so that the inducing action of the latter was reinforced by the presence of iron in the bar; the magnetism of the bar itself varying at each half revolution.

The name *extra-current* is given to an induced current which is developed by the action of a current on itself, that is to say on a part

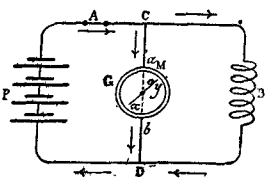

FIG. 252.—Experiment showing the existence of the extra current.

of its own circuit. The existence of this kind of induced currents was investigated by Faraday by the following arrangement. A battery P, Fig. 252, sends a current into a circuit A B C D, across which is a shunt at C D containing the galvanometer G, the other branch of the circuit consisting of a coil of wire B. Under the influence of this continuous current, the needle of the galvanometer is deflected and takes a position of equilibrium $x y$. Then the circuit in A is opened, which interrupts the current; but at this very instant there will be noticed a sudden movement of the needle much more powerful than if the coil B were removed: this more powerful movement is due to the extra-current induced by the current's own inductive action on itself. Extra-currents may in certain cases be more intense than the ordinary current that is produced in the circuit. For example, an ordinary small battery cell is incapable of producing of itself,—because its electromotive force is something under two volts—a spark

of any appreciable length; but if a coil of wire, especially a coil with an iron core, is introduced into the, circuit, then a very bright spark may be observed every time the circuit is broken. This spark is due in reality to the induction of the circuit on itself, each turn in the coil acting as primary to the adjacent ones as secondary to it. All the phenomena of the induction of currents on themselves are grouped under the name of *self-induction.*

All the phenomena of induction that we have just described, and in general all those which have been established, whatever their origin, follow laws which may be summed up in one single statement which is known under the name of Lenz's law from the name of the Russian philosopher who first gave this rule. The following is this Lenz's law :—

If in the neighbourhood of a current or of a magnet, you displace a secondary circuit or a closed conductor, there is developed in this circuit a current, the direction of which is such, that, by the reaction of the induced current on the primary current or on the exciting magnet, it tends to oppose the movement. Or, more briefly, induced currents are always in such a direction as tends to oppose the motion that gave rise to them. It is all the same if the primary current or the magnet is displaced, and the conductor or secondary circuit remains immovable.

We will finish this paragraph by saying what is meant by *induced currents of a higher order.* They are those which are produced by the inducing action of currents, themselves induced by one of the causes that we have before enumerated. Experiment proves that induced currents of the first class, or first order, can induce in neighbouring circuits currents of the second order, and so on. An induced current of the second order being itself the consequence of a momentary current that first suddenly rises and then suddenly falls, is found to consist of two parts, a current that begins and then ceases, followed instantly by a reversed current which also immediately dies away. The two currents follow one another so rapidly in opposite directions that their effects on the needle of the galvanometer neutralize one another, so that all that can be seen is that the galvanometer needle is jerked through a small microscopic distance, and then instantly jerked back again and left at rest. Such currents can however be detected in a telephonic receiver; they can also be

demonstrated to exist by means of their physiological influence, for example by observing the contractions they produce in the muscles of a frog.

[Faraday proved by innumerable experiments that all the phenomena of induction are not merely simple cases of action at a distance, but depend greatly on the medium between the inducing (primary) and the induced (secondary) circuit. In other words induction only takes place from one point to another by reason of action going on in the medium between the two points. The genius of Faraday enabled him to establish the existence of a direct connexion between the phenomena of induction and those of the magnetic *lines of force*, which we have seen to exist around every magnet, and around every conductor in which an electric current is flowing. After proving that there was no inductive action between a magnet and a conducting circuit unless there was also a *relative motion* between the two, Faraday went on to show that the induced current is zero, unless the motion, whether of the magnet or of the conductor, be such that the magnet lines of force are *cut* by the conductor. In fact there is no induced current unless the number of magnetic lines of force that enter the area inclosed by the conducting circuit is altered in the motion. That number may be increased—in which case there will be "inverse" currents generated during the increase,—or it may be decreased,—and in that case "direct" currents will be set up during the decrease. When we remember that every circuit in which there is a current flowing possesses a magnetic field of its own in which there are lines of force running through the circuit; and when also we remember that a spiral coil of many turns—called a solenoïd—when traversed by a current *is* a magnet for the time being, and has poles and lines of force like a magnet, then we shall begin to understand why turning on the primary current acts on the secondary circuit like plunging a magnet pole into it; and why turning off the current acts like suddenly withdrawing a magnet pole out of the secondary circuit. Also this connexion between the magnetic lines of force, and induction effects enables us to understand why the presence of an iron core so immensely helps these induction effects. Iron being a good conductor for the magnetic lines of force, it helps to carry the magnetic lines of force belonging to the primary circuit (or to the inducing magnet, as the case may be) right through the secondary

circuit, and so increases the *rate of cutting* of the magnetic lines by that secondary circuit. The law connecting all this together is very simple. It may be enunciated as follows:—*The total electromotive force induced at any moment in a closed circuit is equal to the rate of decrease in the number of magnetic lines of force which pass through the circuit.* In the case of mutual induction between two circuits, one circuit cuts the other's lines of force. This simple way of looking at the matter makes it self-evident why increasing the strength of the primary current will have the same effect as moving it nearer to the primary. In the case of self-induction the various parts or coils of the circuit cut across the magnetic lines that are due to the other parts of the circuit.—ED.]

§ 3.—*Magnetism of Rotation.*

Arago made in 1824 the following experiment. In order to determine the magnetic intensity of a magnetised needle, he made it oscillate horizontally above a disk of wood bearing a graduated circle. Having repeated the same experiment employing a strip of copper, he found that the diminution of amplitude was much more prompt in the latter rate than in the former; the oscillations had not changed in duration, nor did each oscillation take any longer or shorter time, but a fewer number was necessary to obtain the same reduction of amplitude. With a complete disk of copper, the effect was more marked still: when the needle was suspended at a very small distance from the metallic surface, not more than three or four oscillations were necessary to bring it to rest, whilst they were counted by hundreds when no disk was present.

Arago substituted for the copper disk, disks of other substances. He saw that the amount of "damping" or drag on the needle depended on the nature of these substances, being generally stronger with conducting bodies, such as metals. Nevertheless, water, ice, and apparently even glass would weaken the oscillations of the needle.

Instead of making the needle move, Arago thought of putting in motion the disk over which it was suspended. His foresight in thus

arranging the experiment was justified: the needle deviated in the direction of the rotation; as the velocity of the disk increased, the deviation augmented; and when it had reached 90° the needle took a continued movement of rotation; less rapid than that of the disk, but in the same direction. Arago took care to spread a sheet of paper between the needle and the turning disk, in order to prevent the layer of air contiguous to it from disturbing the phenomenon. The clock-work train of wheels which was used to spin the apparatus was entirely of copper, so as to prevent also all ordinary magnetic attractions.

The experiments may be repeated with the apparatus which is represented in Fig. 253, wherein *a a* is the needle suspended on a pivot; *b b* the turning disk, which receives its movement of rotation from a wheel gearing worked by a handle.

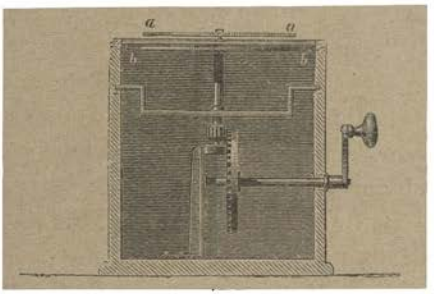

FIG. 253.—Apparatus for showing the magnetism of rotation.

Numerous experiments have shown that the action of the disk in motion is the more energetic as the substance of which it is formed is a good conductor. The effect is greatest, amongst metals, with silver, least with bismuth; also that it is weakened considerably if the disk is hollow, or if it has cuts in its edge, as indicated in Fig. 254.

It is to the whole of these phenomena united that the name *Magnetism of Rotation* is given. They remained unexplained till the discovery of the induction. Babbage and Herschel, repeating the experiments of Arago, could obtain the effects only with disks of metal and of retort carbon, that is to say, only with excellent conductors of electricity. Faraday proved then that they were due to induced currents in the moving disk; currents which by their reaction on the needle tend to move it in the direction of the rotation. He used a

disk of copper twelve inches in diameter, spun upon an axis between the poles of magnets so as to cut their magnetic lines of force. He then found that by connecting the wires from a sensitive galvanometer with strips of copper, which were brought into contact with the edge of the disk, or with its axis, he could obtain deflections, proving that currents were really excited or induced on the disk by spinning it in the magnetic field.

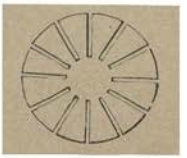

FIG. 254.—Disk of copper slit radially.

We will again take the apparatus which we used to prove the phenomena of dia-magnetism, and we will suspend between the two poles of the electromagnet a cube or ball of copper (Fig. 255) and set it spinning by twisting the thread. As soon as the cube is left to itself the wire, by untwisting, impresses on the cube a rapid spin. If now the current is turned on in the electromagnet the cube is seen to stop suddenly. If the current round the electromagnet is stopped,

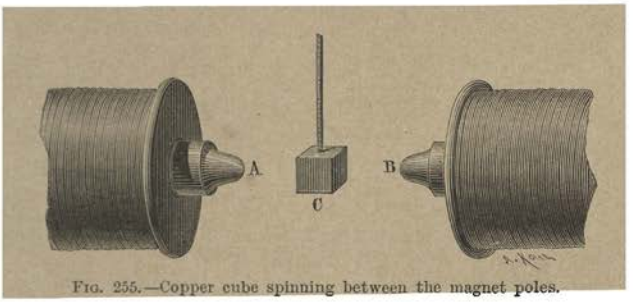

FIG. 255.—Copper cube spinning between the magnet poles.

the motion of rotation in the cube is resumed. The explanation of this experiment is that induced currents develop themselves in the moving mass of copper at the moment when the magnetising current is turned on into the electromagnet; and, according to Lenz's law, the currents will be in such directions that, by their reaction on the magnetic system, tend to stop—and actually do stop—the motion. The suppression of the magnetism of the magnet causes currents to

be induced in a contrary direction, which restore to the cube its first motion of rotation. This experiment, due to Faraday, has also been made by Plücker and was a favourite one with Professor Tyndall.[1]

The resistance which the influence of magnetic action gives to the movement of the cube, placed between the poles of the electromagnet, in the preceding experiment, necessitates the expenditure of a certain amount of work to overcome it. In other words, you may sustain the movement in spite of the magnetic retardation. The work thus spent causes the production of fresh induction currents, and, consequently, a heating of the conductors. This fact has been demonstrated by a beautiful experiment due to Léon Foucault, of which we will give the author's own description.

"Between the poles," he says, "of a strong electromagnet, I have partially inclosed the revolving disk belonging to my rotation apparatus which I named the *gyroscope*, and which had before served for experiments of quite another kind. This disk[2] is placed upon a shaft driven by a pinion and a train of wheels by means of which it can receive a velocity of from 150 to 200 turns in a second. To render the action of the magnet greater, two pole-pieces of soft iron fixed to the bobbins prolong the magnetic poles and concentrate them near the rotating body.

"When the apparatus is going at full speed the current of six or more Bunsen cells is turned on into the electromagnet and stops the motion in a few seconds, as if an invisible brake had been applied to the motion. So far this is simply the experiment of Arago developed by Faraday. But if now the handle is forcibly turned to impart to the apparatus the movement it has lost, the resistance experienced necessitates energy being spent, the equivalent of which in the form of heat accumulates as heat in the interior of the rotating disk.

"By means of a thermometer, which is inserted into the mass, you may follow step by step the progressive rise in the temperature.

[1] Tyndall has compared the resistance experienced by the metallic body between the poles of the electromagnet to that of a viscous mass. Faraday showed that if a piece of sheet copper is moved forwards and backwards between the poles of a powerful electromagnet it meets with a sort of magnetic friction. Tyndall compares it with sawing butter.

[2] Fig. 256 represents the apparatus as it was constructed to reproduce specially the experiment described above; the wheel is replaced by a copper disk which allows the poles of the electromagnet to be put nearer together.

Having taken, for example, the apparatus at the ordinary temperature of 16 degrees centigrade, I have seen the thermometer mount successively to 20, 25, 30, and 34 degrees; but the phenomenon was already developed enough for it to be no longer necessary to employ thermometric instruments; for the heat produced had become sensible to the hand.

"Some days after, the battery being reduced to two cells, a flat disk of red copper was, in two minutes, raised in temperature to 60 degrees.

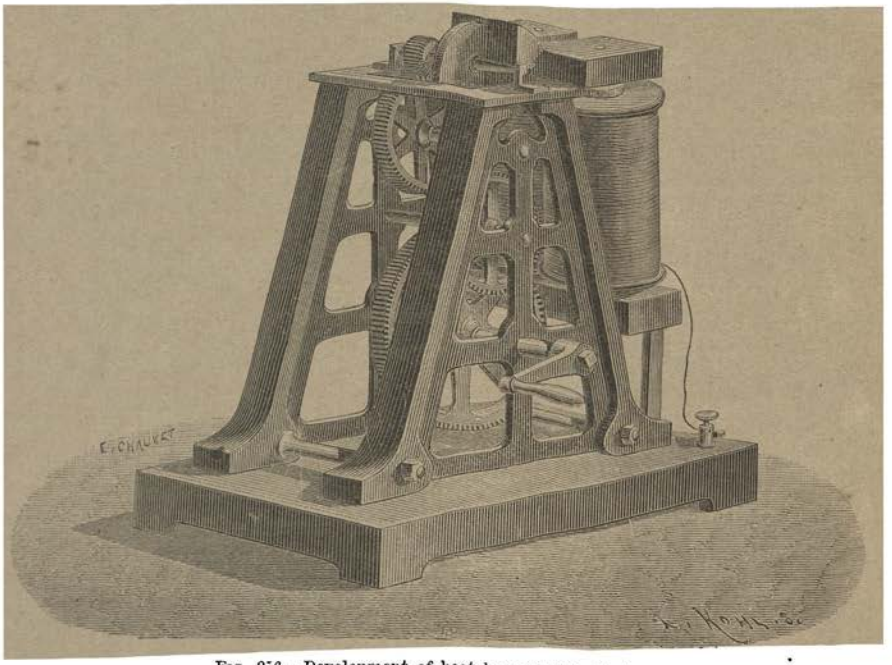

FIG. 256.—Development of heat by magnetic friction.

"If the experiment seems worthy of interest, it will be easy to arrange an apparatus to reproduce, on a larger scale, the phenomenon that I announce. There is no doubt but that by a machine suitably constructed and composed only of permanent magnets, it would be possible to produce high temperatures, and to put under the eyes of the public, assembled in lecture theatres, a curious example of the conversion of work into heat."

This last form given to experiments has indeed been realised by

Tyndall, who describes it in his lectures on *Heat: a Mode of Motion.* At the Royal Institution Professor Tyndall caused a metallic cylinder to turn between the poles of an electromagnet. This cylinder was a copper sheet filled with fusible alloy. The electromagnet being rendered active by the passage of the current, at the end of two minutes the interior mass was melted, and Tyndall was able to pour out the liquefied metal before his audience.

CHAPTER X.

INDUCTION MACHINES.

§ 1.—*Voltaic Induction Apparatus.*

THE discovery of the phenomena of induction almost immediately suggested the construction of apparatus or machines, the object of which was to gather together the currents induced by the mutual action of currents and magnets, or electromagnets, and to obtain by that means all the mechanical, physical, or physiological effects which until then could only be produced by means of voltaic batteries or by friction machines and Leyden jars. And, in short, in 1832, a philosophical instrument maker, Pixii, designed the machine which bears his name. Very soon there followed many machines based on the same principle. The induction apparatus now used, the chief types of which we shall describe, may be divided into two principal classes, according to the mode of production of the currents which they furnish. In the first class it is the current from a battery which induces currents, either in its own circuit, or in a neighbouring one; these machines may be called *volta-electric induction machines.* Ruhmkorf's induction coil is the type of this kind of machine. In the second class we place those machines which require the exercise of mechanical force in presence of a magnet or electromagnet for the production of an induced current. Since in this case induction takes place by the relative movement of a closed circuit and the magnet, the name of *magneto-electric machines* has been given to the machines of this second class. A variety of this class includes those induction machines which only employ no permanent magnet for the production of inducing currents, but which excite their own magnetism. For the sake of distinction, although like the others of their

class, they require magnetism and a moving conductor, they have been called *dynamo-electric machines*. This latter name is now often used to include all machines, whether self-exciting or not, which generate electric currents when driven by mechanical *power*.

Induction Coils.

We will begin with the induction coil, the first idea of which dates from the researches made by Masson and Breguet in 1842. The ordinary induction coil often bears the name of the celebrated constructor, who, by giving it its present form, greatly increased its power: we mean M. Ruhmkorff.

Ruhmkorff's induction coil is represented in Fig. 257. It consists of two separate coils, one to act as primary, the other as secondary. The primary coil is the interior one. It is formed of wire of large diameter, 2 to 3 millimetres, or say $\frac{1}{10}$ to $\frac{1}{8}$ inch gauge, and about 60 to 80 yards long. The two ends of the primary wire emerge at f and f' at two little brass uprights. The secondary coil surrounds the primary, but is separated from it by a stout layer of insulating material; it is formed of extremely fine wire, perhaps as small as 3 thousandths of an inch in thickness, and of an immense number of turns. Small coils may have many hundreds of feet; larger coils will have a mile or so, whilst the largest coils have a secondary wire as much as 200 miles long. The two ends of the secondary coil are attached outside to two metal terminals, A and B, which stand on two glass insulating pillars. In the interior of the inducing or primary coil is placed, as a core, a bundle of thin soft iron wires, bound together at their ends.

Every time that the current from a battery is thrown into the primary circuit and traverses it, entering at f and going out at f', it causes the iron core to become magnetised. The effect on the secondary coil is the same as if the magnetic lines of force of the core were moved up into position, consequently there is in the secondary wire an electromotive force tending to cause a current to circulate round in the inverse direction. Every time the primary current is interrupted, there will arise in the secondary coil another induced current—a direct one. These two currents, the inverse and

the direct, are not necessarily of equal power. By increasing the number of times that the current is turned on and off you will produce a series of instantaneous secondary currents, so closely following one another, and so intense, that the resulting effect will surpass that of the most powerful batteries. We shall see the reason of this presently. We must first show by what mechanism the successive interruptions may be obtained.

There may be seen at L, mounted on a stiff metal spring, a lever of metal with two arms, one of which has a point which touches the surface of the mercury contained in a glass vessel, M, whilst the other ends in a mass of soft iron, which is at a little distance from the

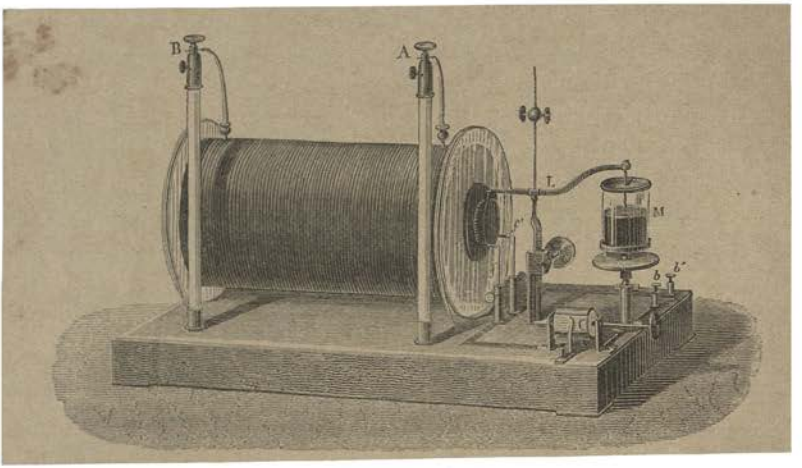

FIG. 257.—Ruhmkorff's induction coil.

iron core in the primary bobbin. When the point touches the surface of the mercury, the mass of iron at the other end is no longer in contact with the core; and conversely if the latter contact takes place, the point does not touch the mercury. Suppose the point to touch the mercury at first, then the current from the battery passes up the pillar which bears the cup of mercury, follows the liquid to the point in contact with it, thence flows along the arm L of the lever, descends along the spring that supports it, and by a metal strip goes to join the wire f' of the primary bobbin. The current passes then into the primary coil, comes back by f, and returns to the other pole of the battery. The contact of the point with the mercury allows the inducing current to pass. But at the moment when this current begins, the

soft iron wires become magnetised, and attract the little lump of iron on the lever, the result of which is to raise the arm bearing the point so that it leaves the surface of the mercury, and the current is broken. Then the magnetism of the core ceases, the bit of iron is no longer attracted: it flies back, and therefore again the point dips into the mercury. The same phenomena will be produced in the same way, so long as the primary coil is in communication with the battery and so the lever is thrown into vibration, and the current is alternately made and broken.

The mercury interruptor which we have just described was designed by Léon Foucault. It is usually employed in the most powerful coils only, and then it is generally worked by a small special battery.

The automatic making and breaking of the primary current may

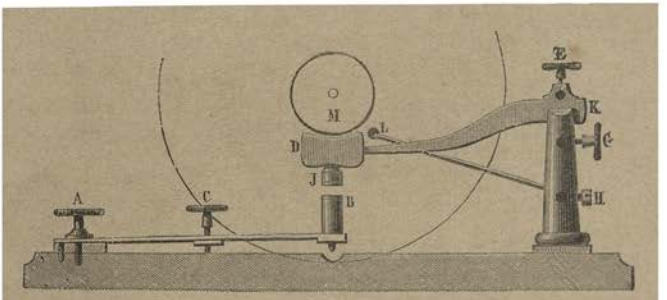

FIG. 258.—Wagner's hammer interruptor, or vibrating "break."

also be produced by using the *hammer interruptor*, shown in Fig. 258. The wire of the primary bobbin L terminates at the insulated metal pillar H G, which supports the hammer K D, the head of which D, carries a platinum contact-piece, J. Before the current passes the hammer rests on the piece B, which serves as an anvil, tipped also with platinum at the top. As soon as the current passes, flowing from the wire L, up the pillar H G, through the hammer and the piece B A, the end M of the iron core becomes magnetised, attracts and raises the hammer, and thus interrupts the current: magnetism ceases, the hammer falls on the anvil, and the current is re-established. To these repeated makings and breakings of the current correspond the currents induced in the exterior secondary coil.

Various sorts of interruptors have been designed, among which

we may mention the Spottiswoode's wheel interruptor, and his and Gordon's special rapid interruptors. These latter give no fewer than 6000 breaks of the current in a second, or even more. We have said nothing of the commutator C, an apparatus, the object of which is either to change the direction of the primary current or to cut it off altogether. Ruhmkorff's *commutator* (Fig. 259) fulfils both of these functions at will; it is at once contact-key and current-reverser, or *rheotrope*. It consists of a boxwood or ivory cylinder, the curved surface of which is partly covered by two copper plates C, C′, thick in the

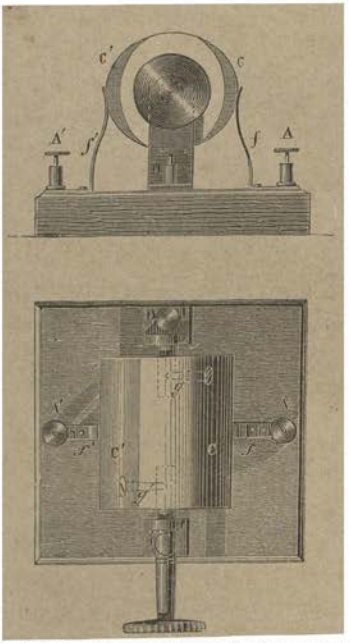

FIG. 259.—Ruhmkorff's commutator in plan and elevation.

middle and thin at the edges. These plates do not meet, but expose between them two parts of the surface of the insulating cylinder. On each side two springs ff' rest laterally against the cylinder when it is turned so as to present to the springs the thick parts of the copper plates. If, by the help of a handle, with which its axle is furnished, you turn the cylinder a quarter round, the ends of the springs will come opposite the ivory instead of touching on the copper plates. In the first position the current can flow; in the second it is interrupted. In fact the current comes from the battery by the screw A;

thence through the spring f it passes to the copper plate C. The latter communicates by a screw g to one of the pivots of the cylinder, then to the button D, and traverses the primary circuit, one end of which is connected to this latter point. It comes back by the other end of the button D′ to the second pivot of the cylinder, and by the screw g' to the plate C′, and then by the spring f' to the terminal A′, whence it returns to the battery. When the springs $f\,f'$ no longer touch the plates C C′ the current cannot pass. The apparatus then serves as a key to switch off the current.

But when the current passes, as we have said, it is only necessary to turn the handle half round to "commute" or change the direction of the flow. For then it is the plate C′ which touches the spring f, and the current will go from D′ to D, instead of going from D to D′.

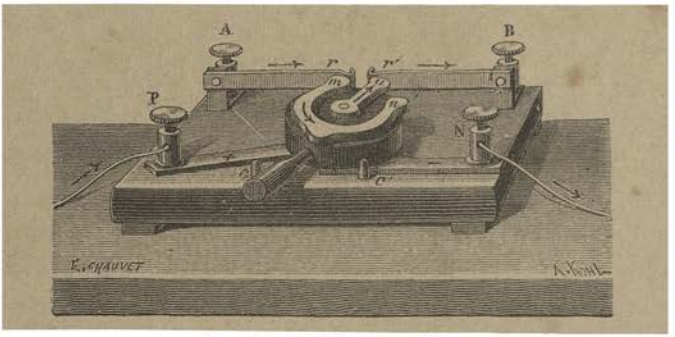

FIG. 260.—Bertin's commutator.

Thus Ruhmkorff's interruptor becomes, at will, a *commutator*, that is to say, an invertor of the current. This is in the primary circuit, but it is clear that it may be employed for other purposes wherever it is necessary to commute or reverse any current. The same is true of Bertin's commutator, which Fig. 260 represents. We will give a summary description of it. A disk of ebonite can be turned about its centre by the help of a handle, which is limited in its movement to the right and the left by two pegs $c\ c'$. A tongue of metal a communicates by the axis of the disk with the terminal P, which receives the positive wire of the battery. Another metallic piece $m\ n$ surrounding the first in the form of a U communicates with the terminal N, to which is attached the wire which goes to the negative pole. In the position indicated by the figure the tongue is in contact

with the spring r', and the end m of the second piece touches the spring r. These two springs are themselves fixed to the terminals B and A, which receive the end of the exterior circuit. It follows that the current goes from P to r' by the tongue a, comes back by A and r to the U-piece, and from there to the terminal N; the direction of the current is marked by the arrows of the figure. If the handle is turned to the right, it is easy to see that the current will be changed, will follow the route P a r A B, to come back by r' and n to the terminal N. If the handle be placed at an equal distance from the pegs c and c', there will be no contact between the springs, the tongue, and the U-piece; the current will be broken. Simple inspection of the position of the movable piece shows the direction of the current and its mode of interruption.

It was mentioned above that the two currents induced, one on the making and the other on the breaking of the primary circuit, would not be necessarily of equal power. The fact is that the induced electromotive force is dependent, as we have seen in the preceding chapter, upon the rate at which the magnetic lines of force are introduced into, or withdrawn from, the secondary coil. Now, as it happens, it takes a longer time to magnetise the core than is necessary for it to be demagnetised, in consequence of the action of the extra-currents in the primary circuit, which tend to oppose the growth of the primary current when the circuit is made, and which tend to sweep the current out suddenly when the circuit is broken. Hence it happens that the rate of disappearance of the magnetic lines is greater at break of circuit than is the rate of growth of the magnetic lines at break of circuit. It therefore follows that the secondary electromotive forces at "make" will be comparatively feeble, whilst those manifested at "break" will be relatively powerful and able to drive a spark through a considerable distance in the air in spite of the enormous resistance to the flow of electricity offered by layers of air.

When Ruhmkorff's coil is at work, if you bring the two ends of the wire of the induced coil sufficiently near each other, you observe a succession of sparks following one another with a rapidity that depends on the rate of vibration of the "break" or hammer. Of the two induced electromotive forces which originate from the successive interruptions of the primary current, the direct current alone produces sparks as we have just seen.

With the earliest coils the length of the sparks attained at most only a few millimetres. By degrees improvements were made, among which we may mention that of Fizeau, which consisted in placing a condenser, a Leyden jar for example, as a shunt to the "break," and which allowed sparks of much greater length to be obtained.

By using as a secondary wire, a length of eighty miles, and by working the coil by aid of ten Bunsen's cells, Ruhmkorff was able to get sparks 20 inches long. Blocks of glass 4 inches thick were pierced through and through by the discharge. The physical effects that are obtained with this powerful machine are truly remarkable: it may be used in place of a friction electric-machine to charge batteries of Leyden jars. In this way Jamin, having charged 120 Leyden jars with four connected coils, each worked by two Bunsen cells, was able to melt and volatilise metal wires of iron, silver, and copper, of more than a yard in length.

In England, induction coils of great dimensions and great power have been constructed. Apps made for the late Mr. Spottiswoode a coil, the weight of which is over 15 hundredweight, the length 47 inches, the exterior diameter 20 inches. The wire of the primary bobbin measures about 600 yards, and it is nearly an inch thick; that of the secondary bobbin measures over 500,000 yards. With five Grove's cells this coil gives sparks $28\frac{1}{2}$ inches in length; with ten cells, the length reaches 36 inches, and with thirty cells, $39\frac{1}{2}$ inches.

The Polytechnic Institute formerly possessed the largest coil that had ever been made. It was 9 feet 9 inches in length; the iron core weighed a hundredweight, and the length of primary wire was 4,300 yards. As to the secondary wire, its diameter is only $\frac{1}{60}$ inch; it measures 300,000 yards in length. This machine worked by forty Bunsen cells, gives sparks of 30 inches' length, which pierce blocks of glass 5 inches thick.

§ 2.—*Dynamo-Electric Machines.*

(*i*) MAGNETO-ELECTRIC MACHINE.

The name *magneto-electric machines* was given by Faraday to some forms of apparatus for producing induction currents by revolving conductors in a magnetic field. He constructed several kinds, which are described in his *Researches*. He thus describes the most important of them:—"A disk of copper, twelve inches in diameter, and about one-fifth of an inch in thickness, fixed upon a brass axis, was mounted in frames so as to allow of revolution, its edge being at the same time introduced more or less between the magnetic poles. The edge of the plate was well amalgamated for the purpose of obtaining a good but movable contact, and a part round the axis was also prepared in a similar manner. Conductors or electric 'collectors' of copper and lead were constructed so as to come in contact with the edge of the copper disk." A collector was put in contact with the axle, and another with the edge of the disk at the point immediately between the magnet poles. The magnet used was a powerful one, formerly constructed by the famous Dr. Gowin Knight. It was composed of about 450 bar magnets, each 15 inches long, 1 inch wide, and half an inch thick. Iron pole-pieces were placed on its poles to bring the magnetic lines more intensely together where they passed through the disk.

Pixii's machine, as we have before said, was the first induction machine that was put into the market. For that reason it deserves mention, though its use has long been abandoned.

A (Fig. 261) is a strong permanent horse-shoe magnet mounted on a vertical axle C, and free to turn round this axle by the action of a handle and gear R and P. Above the magnet is set a fixed bobbin, or electromagnet, formed of two cores of soft iron, round which are wound an insulated copper wire, the two poles being placed at a little distance from the poles of the magnet A. As the latter turns, its poles alternately approach and recede from the poles of the electromagnet B B'. There then arises in the wire of the latter an induced current, the direction of which changes at each half-turn.

By the aid of a commutator, C, conveniently placed upon the spindle, the induced currents are all commuted into the same direction, so that though the wires, *a* and *b*, of the electromagnet are at first traversed alternately by oppositely-directed currents, the currents as they issue from the commutator flow successively in the same direction.

Pixii's apparatus had the inconvenience of being troublesome to work, because of the weight of the magnet. It was found useful to

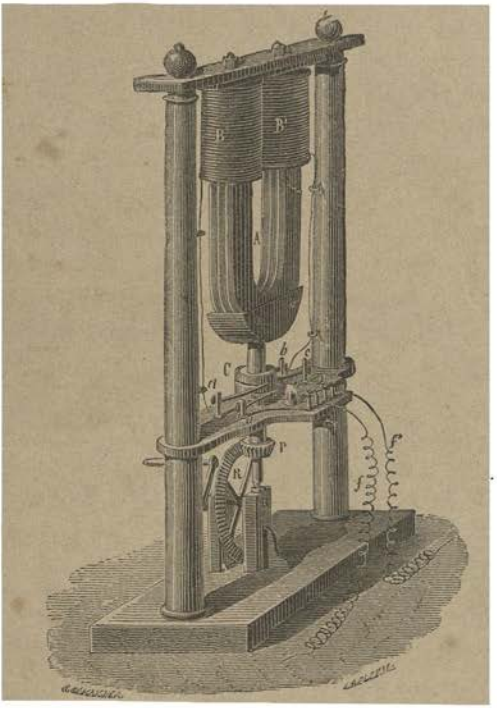

FIG 261.—Pixii's magneto-electric machine.

increase the weight of this permanent magnet, whilst the electromagnet could be made less massive. This inconvenience suggested the idea of moving the latter, and on the contrary, fixing the magnet. Hence a simple modification due to Saxton, who further placed the magnet in a horizontal plane, and made the induced bobbin move round an axle situated in this plane.

Afterwards came Clarke, who, whilst leaving the magnet vertical,

made the inducing bobbin move opposite the face of the poles. In almost all modern machines it is the coil or *armature* which revolves; whilst the magnet that furnishes the magnetic field—now usually called the *field-magnet*—is made very massive and stands still.

Clarke's machine is represented in Fig. 262. A powerful magnet, A B, composed of many plates in the horseshoe form, is solidly fixed to a vertical wooden support, so as to present its two poles opposite to two bobbins, each of them furnished with a core of soft iron. The

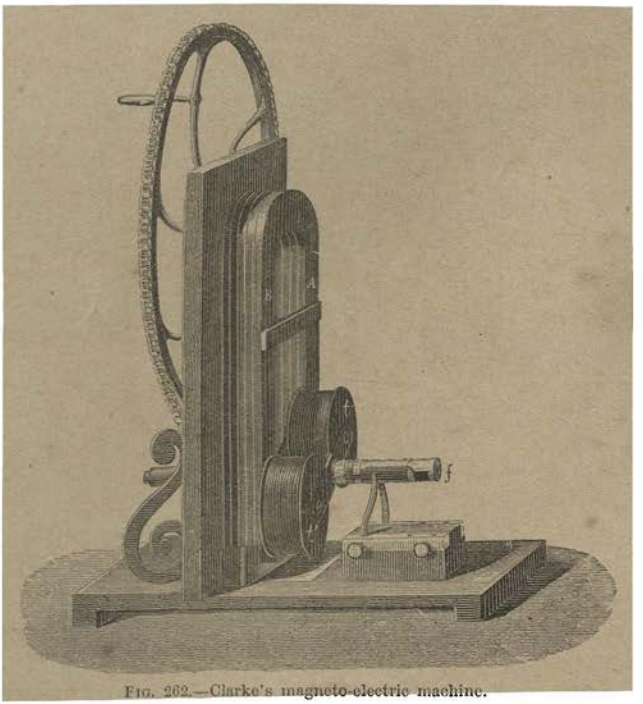

FIG. 262.—Clarke's magneto-electric machine.

two iron cores are joined together on the side of the magnet by a copper plate, and on the opposite side by an iron yoke *t t*. The two bobbins thus arranged are nothing else, as you may see, but an electromagnet; they can be rotated together around a horizontal axle *f*, which passes between the poles of the magnet, and engages with a driving chain and wheel behind the back board. When you set the machine in motion the two bobbins turn round their common axle, so that at each half revolution they come opposite poles of the

field-magnet A B. As the wires of which the coils are formed are wound in contrary directions (one of them left-handed, the other right-handed), the currents induced in each of them, by their approach to the two contrary poles of the fixed magnet, are in the same direction. The directions of these currents change when the coils are receding from the poles, but it changes at the same time in both, so that at every instant the currents are either both direct or both inverse.

The presence of the iron cores promotes the effect by conducting the magnetic lines of force into and out of the revolving coils. The two wires of the coils end in the apparatus called a *commutator*, which serves at will, as we have seen, either to keep the current in the same

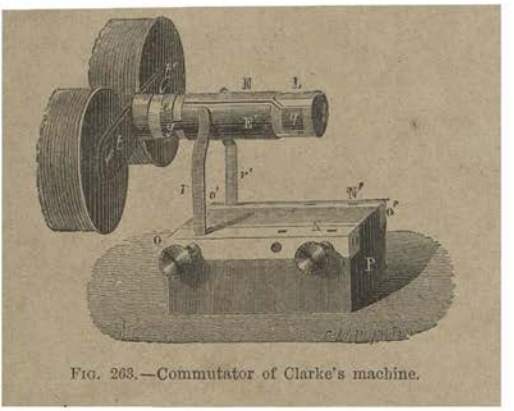

FIG. 263.—Commutator of Clarke's machine.

direction during the whole time of the movement, or to allow the direction of this current to change alternately at each half revolution. In this instance it serves the former purpose.

Fig. 263 represents this commutator on a larger scale. In the prolongation of the axle of rotation of the coils there is mounted a cylinder of insulating material such as ivory, on the surface of which are fixed two metal plates, E E′, in the form of the two halves of a split tube. The spaces which separate these plates are diametrically opposite, and in the plane of the axles of the two coils. One of these plates E′ communicates by a tongue *g*, with a collar *e*, and with one of the ends of the wire of the electromagnet (*d d′* of Fig. 264); the other plate E, with the other end, by the means of a metal axle inside and a screw *v* which traverses the insulating piece. Two springs, *r r′*,

press against the two semicircular plates, and communicate with the exterior circuit. At each semi-revolution, and at the exact moment when the induced currents change their direction, the communication of the wires is reversed, since the spring r which touches the semicircular plate E′ now comes to rest on the plate E, and also r' rests in its turn on E′. The moment of inversion therefore coincides with the change of direction of the induced currents and consequently the currents sent to the exterior circuit preserve the same direction.

With Clarke's machine all the effects of ordinary currents may be produced, but with an electromotive force greater than that of

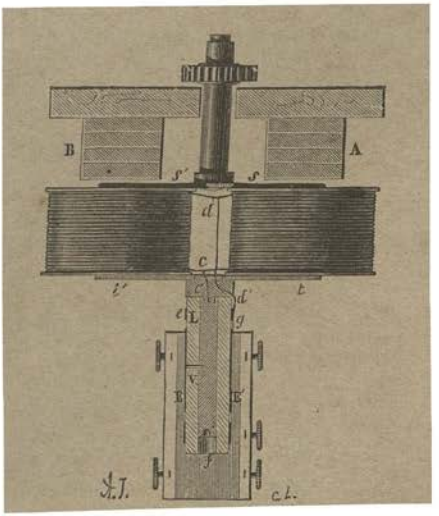

FIG. 264.—Clarke's commutator: horizontal section.

any single kind of batteries. Special arrangements are made for producing, either violent shocks or sparks, or calorific effects, or in some cases chemical decompositions, as may be desired. In the last case, the springs are so arranged that the direction of the current remains constant; in the others, on the contrary, the currents may be alternating in direction, the springs being arranged to collect them without commuting them.

Physiological effects, which demand great electromotive force, and for which a coil with fine and very long wire is employed, are heightened by the sudden rupture of the induced currents, and the production of the extra-current. A special arrangement of the com-

mutator allows of obtaining this result. You then add a third spring which rests on the plate q Fig. 264. A person wishing to receive the shock holds in his hand the wires furnished with handles, which pass from N to N'. As soon as the spring touches the plate, the current is interrupted, and ceases to pass to the body of the observer, which offers so great a resistance.

When it is necessary to obtain calorific or luminous phenomena, coils made of short thick wires are substituted. In these as Fig. 265 shows, the two coils are joined up in parallel with one another. Towards 1849, Nollet, Professor of Physics at the Military School of Brussels, made, after the principles of Clarke's machine, an induction

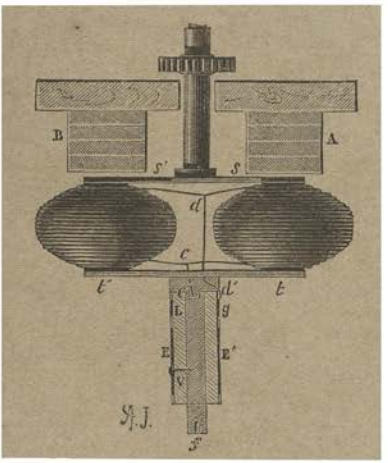

FIG. 265.—Thick wire armature for use in Clarke's machine.

machine, by which currents could be produced of great strength. But he died before realising his project, and it was a workman, Van Malderen, a collaborator of the inventor, who erected Nollet's machine, long used by the Alliance Company for the production of electric light. Here are the essential arrangements of it.

Sixteen bobbins with regular spaces between (Fig. 266), are fixed at the circumference of a bronze wheel; this wheel is movable, mounted on a shaft driven by a belt and pulleys from a steam-engine. The wheel carrying the bobbins turns between two rows of horseshoe magnets, eight in each row, arranged on a circular frame so that the eight magnets present at once their sixteen poles, at

regular distances, in front of the poles of the sixteen coils which approach and retire at the same time from each of them. In the same machine the number of wheels, coils, and magnets, is generally duplicated, other sets being mounted on the same shaft and frame. In the drawing there are eight ranks of magnets, with eight internal wheels. The ends of the wires of the coils are brought down to plates of wood, fixed on the shaft and are united either in series or parallel. The whole complex armature therefore consists of 128 bobbins appropriately grouped around a single shaft. When the

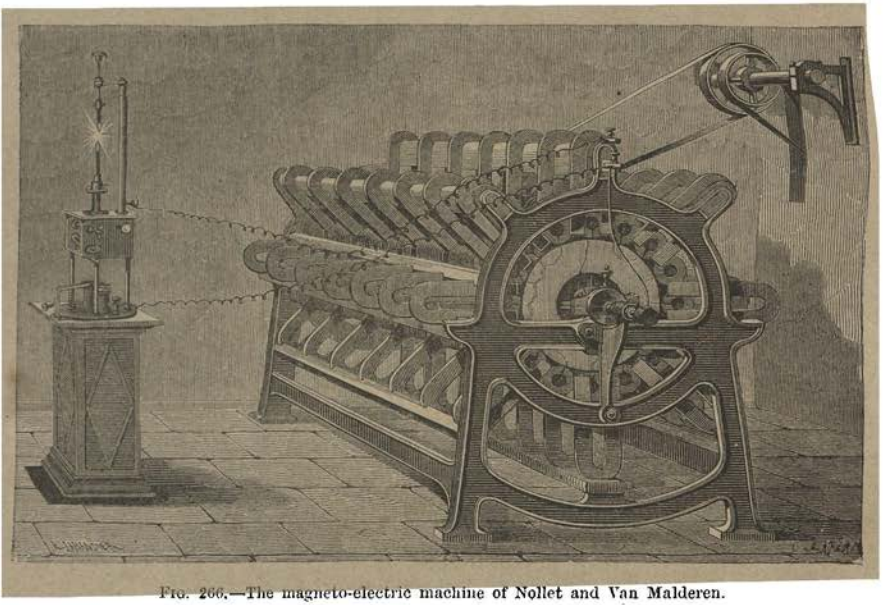

FIG. 266.—The magneto-electric machine of Nollet and Van Malderen.

machine is at work, each time that the movement brings the coils in face of the poles of the magnets, the induced currents cease, and change in direction; these currents are developed in one direction, as s on as the coils approach a north pole, and in a contrary direction as they approach a south pole. Between the two poles of the same magnet, the induced current keeps the same direction. The electromotive force is greatest at the instant when the magnetism is changing most rapidly, which occurs just when the bobbins are leaving the neighbourhood of the poles. By the aid of a commutator the whole

of the currents can be made to flow in the same direction in the outer circuit that they supply.

In Fig. 266, which represents the magneto-electric machine of Nollet and Van Malderen, there are 128 rotating coils, and 64 fixed magnets. A steam-engine drives the shaft with a speed of 300 to 400 revolutions per minute, which corresponds to 80 or 100 inversions of the current per second.

The modern machine of De Méritens presents nearly the same form and the same arrangement as the Alliance machine, as may be

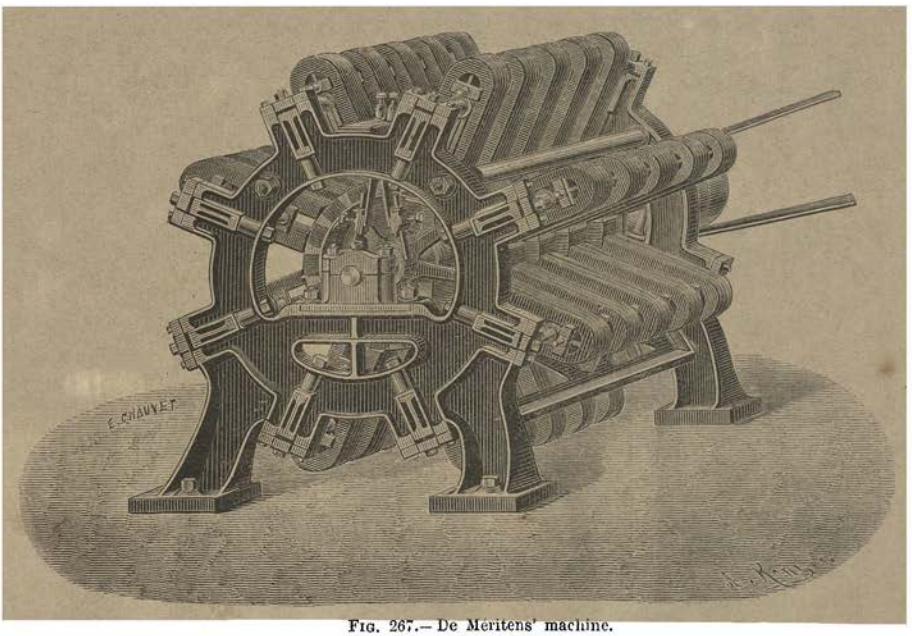

FIG. 267.— De Méritens' machine.

seen by Fig. 267. It is formed also of coils turning before fixed steel magnets; but these coils are placed so as to be acted upon by the end faces of the magnets instead of their lateral faces. These coils are moreover wound upon ring-shaped iron cores: not as separate bobbins. With five movable wheels with sixteen coils on each, there are only forty fixed magnets, each of which is made up of a bundle of eight steel plates. We shall have occasion to speak again of the machines of Nollet and De Méritens, in connection with the electric lighting of lighthouses.

Werner Siemens in 1855 devised a magneto-electric induction machine based on the same principle as Clarke's; but he made an important modification in the bobbin, which added greatly to the power of the apparatus, without its size being much altered. Figs.

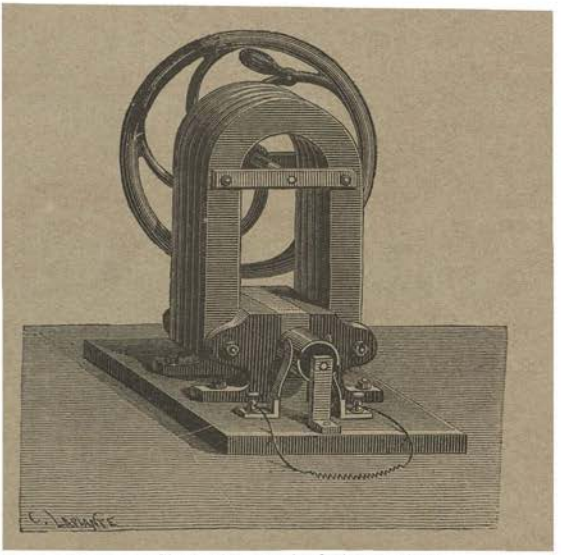

FIG. 268.—Siemens's magneto-electric machine.

269 and 270 give, the first the outside, the second a section of the bobbin; they show in what the modification introduced by Siemens consists. The wire is coiled longitudinally in two grooves cut in the sides of an iron cylinder, or core, *a b*, so that the coils are parallel to the axis of the cylinder. The bobbin is mounted so as to turn rapidly

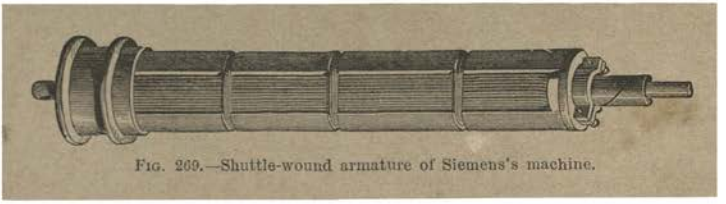

FIG. 269.—Shuttle-wound armature of Siemens's machine.

round its axis; at each half revolution, it presents its poles *a b* (which are the parts of the iron core that are uncovered) to the pieces A and and B, of soft iron forming the pole-pieces of the field magnet. This is made up of a bundle of horse-shoe magnets, the polar parts of

which are ranged along the whole length of the bobbin. Thanks to this arrangement, the action of the poles of the field magnet on the wire of the bobbin is much more powerful, as more magnetic lines now cross through the coil from side to side, and the intensity of the induced currents is considerably increased. Moreover, the stability of

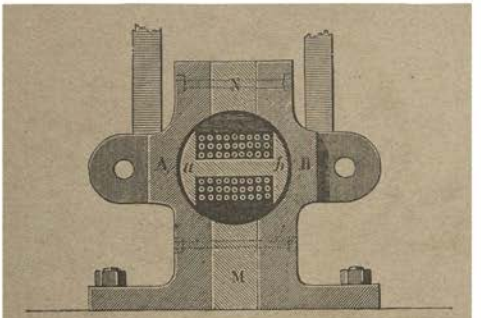

FIG. 270.—Section of Siemens's armature in position.

the apparatus resulting from its form and its position, allows of greater speed being given to it. Fig. 271 represents the commutator which inverts the direction of the currents, a direction which without this adjunct would change at each half-revolution, as in Nollet's machines. In the diagram showing the exterior of the armature, this commutator is slightly differently formed; but they are both con-

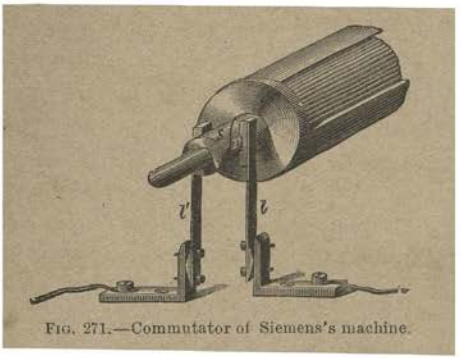

FIG. 271.—Commutator of Siemens's machine.

structed after the same principles as those of Clarke's machine, already described, and their action can be explained in the same way.

Wilde's machine, Fig. 272, is nothing but the combination of two of Siemens's machines, but with an important modification which greatly increases the power of the machine.

In this machine the main field magnets are no longer permanent magnets of steel, but are powerful electromagnets wound with coils; and these coils A B, are excited by means of currents furnished by a separate small auxiliary machine having permanent magnets, mounted

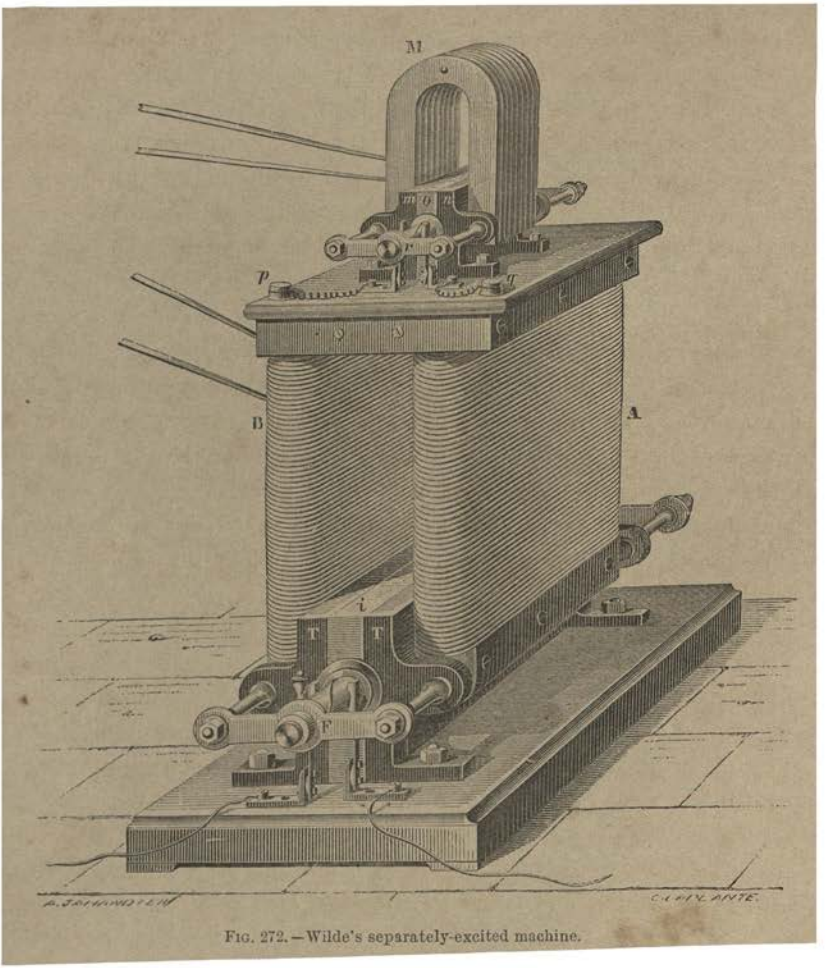

FIG. 272.—Wilde's separately-excited machine.

on the top of the larger machine. M is the permanent magnet of the small auxiliary machine, and *m n* are its pole-pieces of soft iron. The induced currents collected by the small commutator go through the terminals *p q* to the wire of the large electromagnet A B. The massive plates of soft iron, which form this latter, united at their

upper ends by a yoke of the same substance, rest at the bottom on the bars T T, which run the length of the large armature. This is of nearly three times the size the armature of the little auxiliary machine, or "exciter." The magnetism of the main machine is also much more powerful than that of the permanent magnets of the little exciter. The advantage of Wilde's machine lies then entirely in this fact, that an electromagnet having soft iron cores may be magnetised to a much higher degree than can the steel magnets of an equal size or cost. The speed for these machines was 1500 revolutions per minute for the main armature, and 2400 for the armature of the exciter. The inventor, Wilde, constructed a triple machine, that is one in which a small exciter magnetises the electromagnet of a larger machine, the armature of which in turn furnished a magnetising current to a third machine. It required a steam-engine of fifteen-horse power to put it in movement, and was so powerful that it melted a bar of platinum, six millimetres in diameter and sixty-four centimetres in length. It has been far surpassed of late years, however. In 1870, Gramme, French engineer, designed a magneto-electric machine, in which for the separate bobbins of the Alliance machine there was substituted an armature in the form of a ring. A similar design, only differing in having iron teeth to the ring, had been devised in 1864 by Professor Pacinotti, but had dropped out of sight. None of the earlier machines, not even those provided with commutators, gave really continuous currents; the simple commutator merely inverted the alternating currents, and made them into a succession of separate currents all flowing in the same direction. Gramme's ring-armature gave really continuous currents.

In Fig. 273 S N are the poles of the field magnet of the Gramme machine. Between these two poles a soft iron ring is made to rotate around its centre, and in its own plane. By the fact of the position of its different parts with regard to the magnet, the ring has always a north pole which is developed by the influence of the pole S, opposite to it, and a south pole opposite to the pole N, whilst at the extremities of the diameter, parallel to the arms of the magnet, there exists a neutral line. Round the ring are wound the coils, the wires of which are united so as to form a continuous circuit, the coils being joined up in series.

Let us think of one of them, and examine what happens to it during its rotation. When the coil starts from the middle, where the neutral line is, and advances to E on the side of the S pole, it is cutting the magnetic lines of force between the ring and the s pole, and there is developed in it an induced electromotive force, the intensity of which increases (while preserving the same direction) as the coil advances towards S. From that moment, as it proceeds towards E, the induced current begins to diminish its intensity; but the direction of the current remains the same, because the coil in turning round presents its other end to the pole of the field-magnet. When the coil has arrived at an equal distance from the two poles, the induced current changes. In the second half of the rotation, the same things happen, except that the direction of the induced

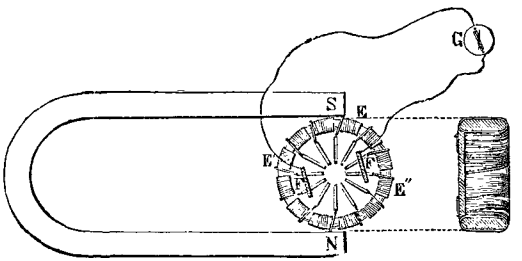

FIG. 273.—Diagram of Gramme's magneto-electric machine.

current is opposed to the direction of the current induced during the first half.

If now, instead of considering one coil only, you consider them all together, it is easy to understand that those which are situated in the upper half of the ring, are traversed by induced currents of an intensity which varies with the position of the coils. Now these currents join into one, since their direction is the same, and the coils are arranged or connected in series. On the other hand, all the coils of the lower half circumference of the ring are traversed by a series of induced currents, opposite to the first, but also joining each other.

By gathering together, and uniting in the same circuit these two sets of currents you obtain a continuous current, for there will be no instant when some of the coils are not in action. To attain this

result a series of metallic pieces is employed, each of them being insulated from the others, and each is attached to the end of a wire, coming from the junction between the end of one coil and the beginning of the next coil. In the diagram they are arranged radially, there being as many of them as there are separate coils round the circumference of the ring. In practice they are not arranged radially, but are set parallel to the shaft and form a kind of cylinder of small diameter, being mounted upon a hub of insulating material. This arrangement is also sometimes called a "commutator" or "collector." The details of the Gramme ring are shown in Fig. 274, where the metal bars R R constitute parts of this collector.

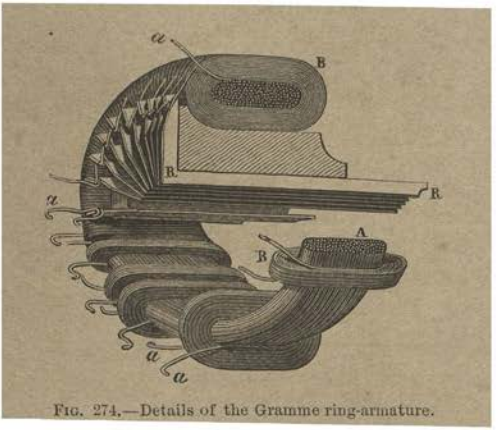

FIG. 274.—Details of the Gramme ring-armature.

The collecting springs or "brushes" are made of wires or strips of metal; they rest on the collector, one on each side, at the points that correspond to the place where the coils have their neutral position about half way between the poles of the field-magnet. By this arrangement, the induced currents in the two halves of the ring are united to supply one large current to the exterior circuit, just in the same way as the currents of two sets of cells may be united at the ends of the rows of cells, in parallel, to furnish one current of double strength.

Fig. 275 represents a model of Gramme's magneto-electric machine, wherein a laminated field-magnet is used. This form is very convenient as a laboratory machine, as it can be easily worked by hand, and is useful for many experiments, without requiring the preparations necessary when batteries are used.

Magneto-electric machines have been used for electro-plating since about the year 1847, and, for electric lighting since 1860.

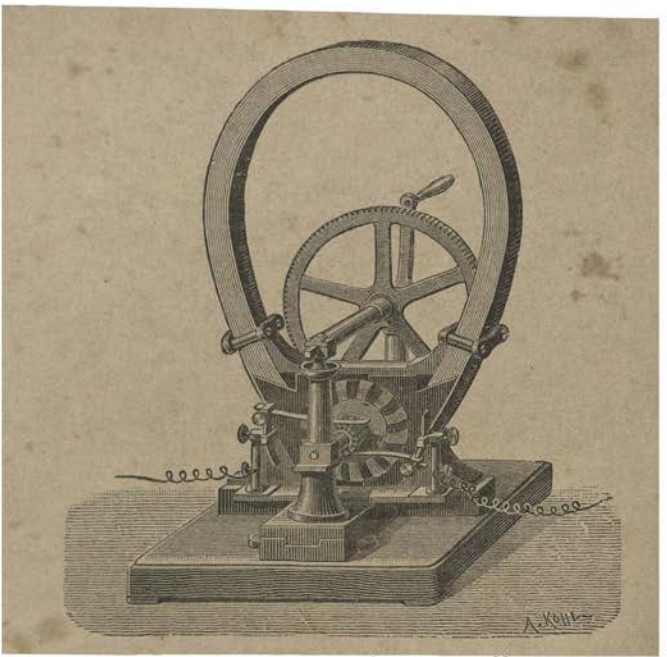

FIG. 275.—Gramme machine with laminated field-magnet.

(*ii*). DYNAMO-ELECTRIC MACHINES.

Up to the present point the induction machines that we have described, have all had for their field-magnet a permanent magnet of steel, except the machine of Wilde, in which a separate "exciter," itself a small permanent-magnet machine, was used. We now turn to those self-exciting machines in which the magnetising current is that which is obtained from the machine's own armature. The idea of making use of the machine's own currents to magnetise its own field-magnets occurred first to Brett, then to Hjörth, then to Varley, who patented a machine on this principle in December 1866. The same idea came almost simultaneously into the minds of Sir C. Wheatstone, and of Dr. Werner Siemens, in the beginning of the year 1867. To appreciate the importance of this discovery, it must

be remembered that with an equal weight the inducing power of an electromagnet is much greater than that of a permanent magnet, because iron can be magnetised more powerfully than steel can with equal magnetising power.

The essential action at the starting of a self-exciting machine is this: at first there is little or no magnetism, because the residual magnetic properties of soft iron are feeble, and the earth's magnetic field is also weak. But, however little magnetism there is to begin with, when the armature is set spinning its coils cut across the few magnetic lines that are present, and thereby weak currents are induced. If these weak currents are then caused to flow round the field-magnet they excite a little more magnetism in it, and the inductive effect is stronger. These stronger currents excite the magnet still more strongly, the increased magnetism reacting to produce a still stronger current, until a very high degree of magnetisation has been reached. Self-exciting machines of this kind require very little power to spin them round before their magnetism is excited. Directly the circuit is closed so that they excite their field magnets, much power is required to drive them. The term *dynamo-electric machines* was first suggested by Dr. Werner Siemens. They may be grouped into several classes, according to whether the whole or only a part of their currents is caused to flow round the field-magnet coils. When a dynamo is arranged so that the field-magnet coils are connected in series with the armature and the rest of the circuit, then the whole armature current flows round the field-magnet. Such machines are called *series-wound dynamos*, and their field-magnets must be wound with thick wire to carry the whole current. If the coils of the field-magnet are arranged as a shunt to the rest of the machine so that part of the current generated in the armature never goes to the lamps in the circuit, but is diverted to flow back through the field magnet coils and magnetise them, then such machines are called *shunt-wound dynamos*. This was the kind first suggested by Wheatstone. In the best shunt-dynamos only from 4 to 8 per cent. of the whole current is thus diverted to magnetise the field-magnets; and as only a small current is so diverted the coils must consist of a very large number of windings, and the wire may be relatively thin.

For the purpose of supplying currents at a perfectly uniform

potential (or "pressure") to a system of incandescent electric lamps, dynamos are now often made with two sets of field-magnet coils, some of thick wire in series with the main circuit, others of thin wire connected as a shunt. Such machines are called *compound-wound dynamos*.

As mentioned above, the self-exciting principle was known in the year 1867. The first practical application of this principle was made shortly afterwards, by the English instrument-maker Ladd.

Ladd's machine, except in the arrangement of its parts, re-

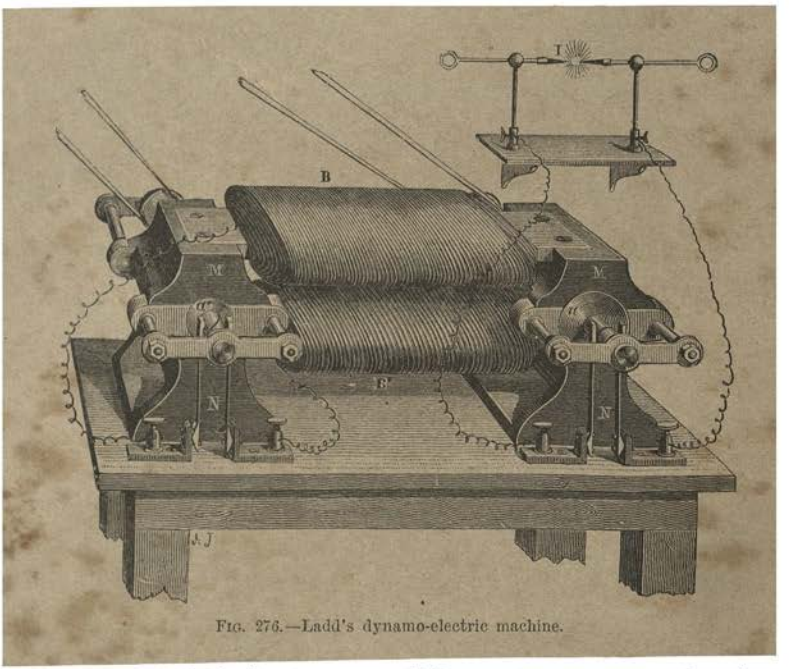

FIG. 276.—Ladd's dynamo-electric machine.

sembles that of Wilde, having two of Siemens's armatures; but there is no steel magnet provided for the exciting armature.

The field-magnet B B′, Fig. 276, is formed of two large iron plates surrounded with wire, and thus forming two straight, parallel electro-magnets. The pole-pieces of soft iron, M and N, which you see on the left, embrace a small Siemens's armature, a', which serves as an exciter, and sends its induced currents into the field-magnet coils to magnetise them. On the right there are also two pole-pieces, M and N, which embrace the large Siemens's armature. The currents induced by this second armature pass into the main circuit to supply electric

light or other useful applications. The two armatures, a and a', are arranged so that when the first presents its ungrooved sides to the pole pieces of the electro-magnets, the other bobbin is at right angles. Two pulleys driven from the same drum put the two armatures into motion.

At first, when making his self-exciting dynamo-machine, Varley employed a battery to excite the magnets; but it was soon discovered that this was needless, as there was sufficient initial magnetism in the iron of the cores to enable the machine to excite itself.

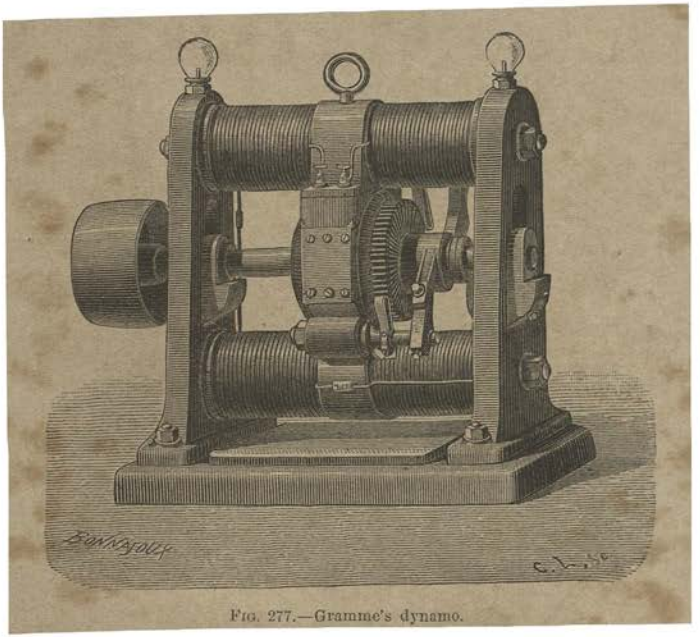

FIG. 277.—Gramme's dynamo.

Hundreds of different improvements have been made in dynamo-machines: of these we can touch only a few that have become prominent as types.

Among these, Gramme's dynamos, of which Fig. 277 represents a model, have from the first (1870), met with great success. The principle is the same as in Gramme's magneto-machine, which we have already described. The use of the ring armature permits of the production of continuous currents, and the substitution of electro-magnets for permanent magnets has allowed of the power being greatly increased. It is moreover found that when field-magnets of

relatively very great power are employed, there is less trouble with the armature giving sparks at the brushes. In machines of the type of Fig. 277, the Gramme ring revolves on a horizontal shaft, which is put in movement by a pulley driven by a belt. The armature rotates between two pieces of soft iron, which are the pole-pieces of the field magnets, and which surround the ring for about three-quarters of its circumference, so as to obtain a proper distribution of the magnetic field and to increase the induction effects. There are two pairs of magnetising coils, one pair at the top, the other at the bottom of the machine. They are so connected that the iron pole-piece at the top becomes a magnetic pole of one kind—say a north pole, while the lower pole piece becomes a pole of the other kind. The induced current which is produced in the revolving ring armature passes at first from the brushes into the coils of the field-magnet, the magnetic power of which it strengthens, and so flows away into the external circuit, to be used according to the purpose of the machine for lighting, or electro-plating, or other useful end.

[Numerous dynamo-electric machines constructed after the same principles as Gramme's machine are in use at this day, but they have been greatly improved, both mechanically and electrically, especially by English and American engineers.]

The Hefner-Alteneck machine, Fig. 278, thus called from the name of its inventor, Von Hefner Alteneck, an engineer of the firm of Siemens of Berlin, differs from Gramme's machine in having a drum-like armature instead of a ring, and in the mode of coiling of the wires on the drum. The wires are wound from end to end outside, and constitute as in the ring armatures, a closed circuit. The cores of the field-magnets in this type of machine are bars of wrought iron, which run the whole length of the machine but are arched up where they envelope the armature above and below. The collector and the brushes are like those of Gramme's machine.

More recently the Siemens's dynamos have been constructed with much more substantial field-magnets of cast iron.

The Brush dynamo, Fig. 279, has a Pacinotti ring armature, with only eight or twelve coils separated by projecting iron teeth, and connected together across two and two, instead of being joined up consecutively as in the Gramme rings. This armature turns between the poles of two electro-magnets of horse-shoe shape; they are

oblong in form, and so arranged that their similar poles lie opposite each other. The induced currents are consequently inverse in the two halves of the ring that revolves between them.

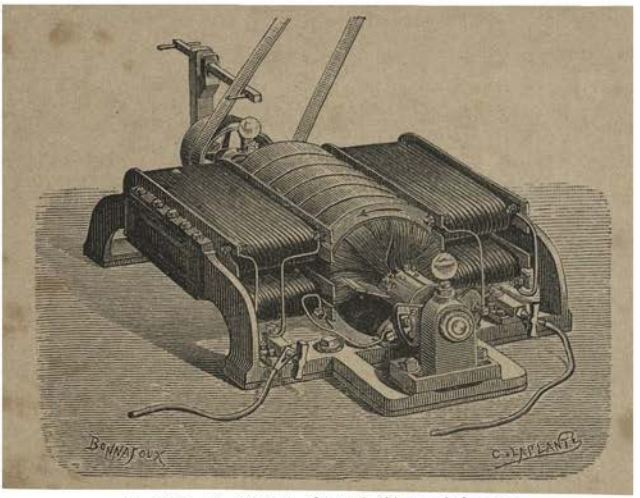

FIG. 278.—The Hefner-Alteneck (Siemens) dynamo.

In another type of armature, known as Lontin's, the coils are arranged neither in a ring nor as a drum, but are separately wound

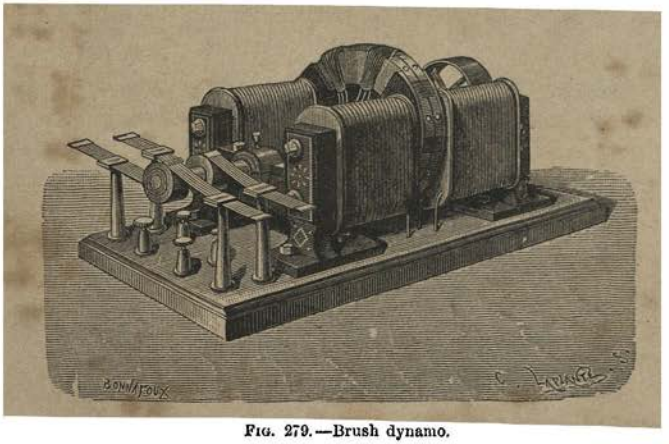

FIG. 279.—Brush dynamo.

upon a number of radially-protruding poles. This type is now abandoned.

Edison's dynamo, a drawing of which is shown in Fig. 280, has a very substantial armature constructed on the Hefner-Alteneck prin-

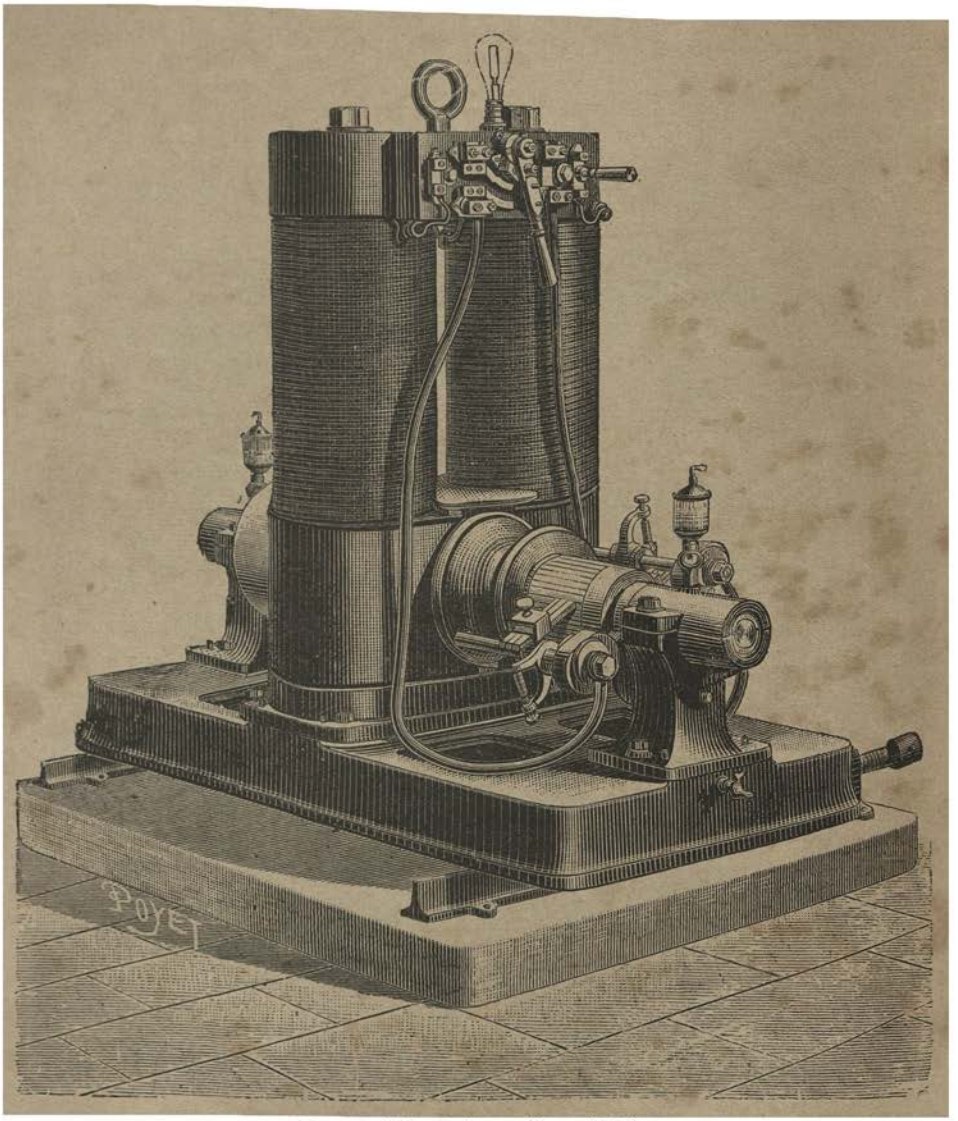

FIG. 280.—Edison's dynamo (type of 1884).

ciple. The field-magnets are solid iron pillars, connected at the top by a heavy yoke of iron. In this figure the usual arrangement of

collectors, made up of a set of parallel bars of hard copper, may be seen; also the usual arrangement of the collecting brushes.

Another favourite modern type of dynamo is depicted in Fig. 281. This is the "Manchester" dynamo, designed by the brothers Dr.

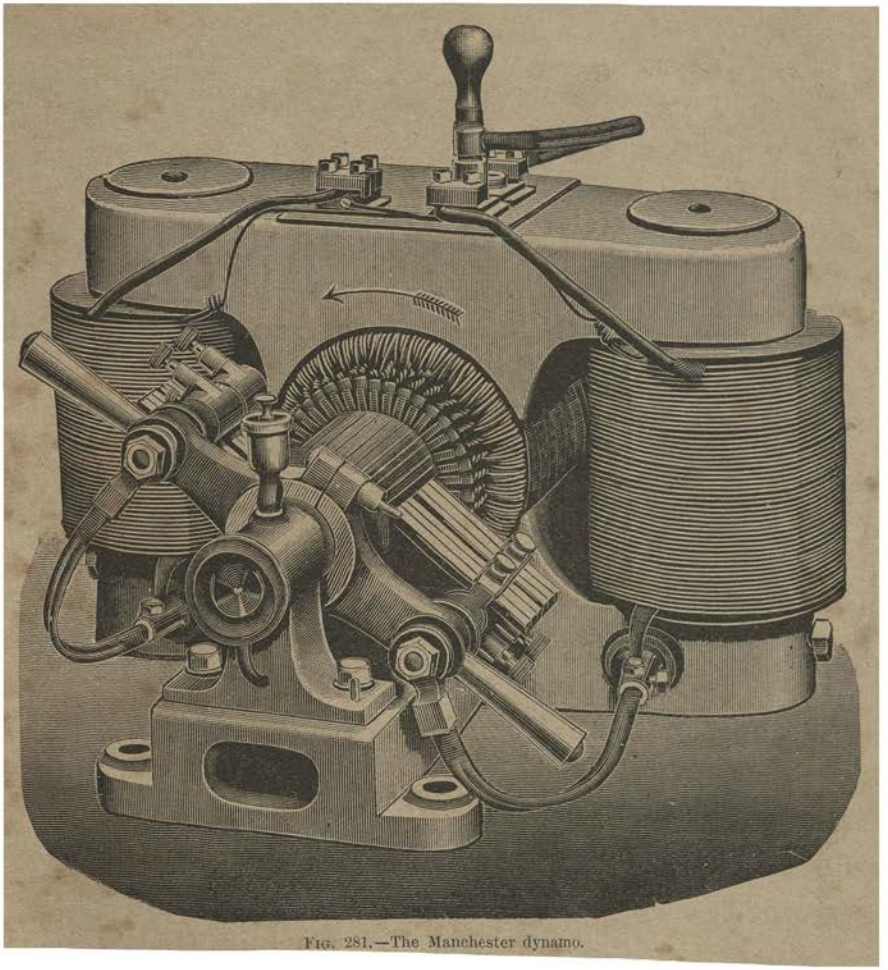

FIG. 281.—The Manchester dynamo.

John and Dr. Edward Hopkinson. The armature is a Gramme ring, carefully constructed for good mechanical driving, proper insulation, and ventilation. The field magnets are very compact, the yoke and base being of cast iron, and the upright cores of wrought iron.

CHAPTER XI.

LUMINOUS ELECTRIC DISCHARGES.

§ 1.—*Electric Sparks.*

ELECTRIC discharges, as we have often had occasion to mention, give rise more often than not to a production of light. The earliest experimenters observed sparks to issue from electrified bodies when their surface was touched by the finger. Otto von Guericke, Dr. Wall, Gray, Dufay, and Hauksbee began the study of this peculiar manifestation of the powers of electricity. Franklin saw an electric discharge escaping under the form of a plume or brush of light from a metal point; he did more—he discovered what Gray and Wall only foresaw, the identity of the feeble spark, and of the sharp crackling which accompanies it, with the grand phenomena of lightning and thunder. Later Sir Humphrey Davy, using the current of a powerful battery, showed how it was possible to produce between two pencils of charcoal attached to the poles the most intense of known artificial lights, the voltaic arc.

All the luminous effects of electric discharges are of great interest: their varied appearance, the study of the conditions in which they are produced, are as important to consider, in a purely scientific point of view, as are from a practical point of view the numerous applications of which electric light has for some time past been the object. We have already described some of these effects in connection with the curious experiments that can be made by means of electric machines, condensers, &c. It is the time, now that we know what are the most powerful apparatus for producing currents, to complete what we have to say about electric light. We will begin

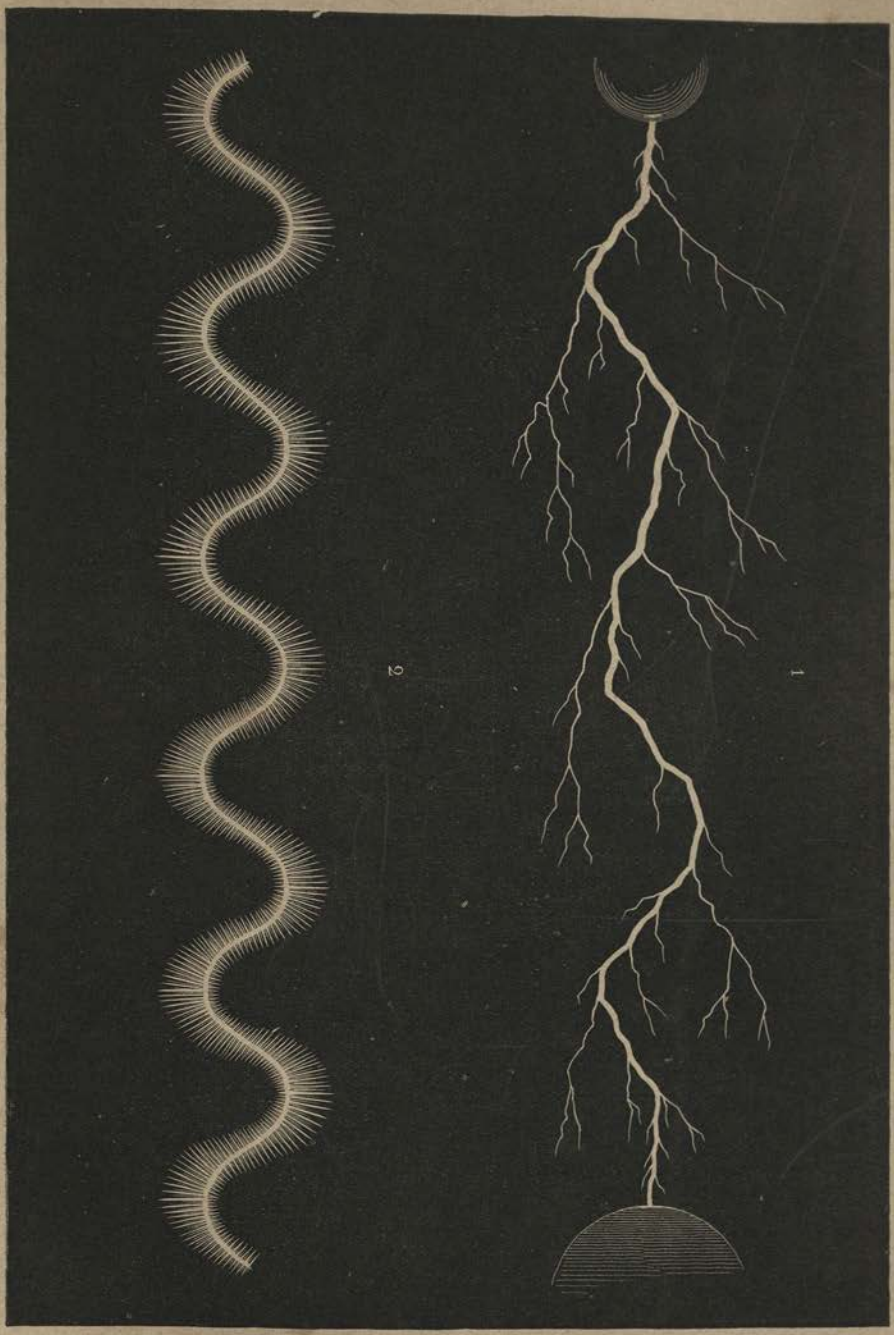

PLATE VII.—THE ELECTRIC SPARK.

Sinuous and branching sparks. Drawn by Van Marum.

with the *spark* which is produced, as we have seen, every time that two bodies charged with opposite electrifications, and with sufficient difference of potential between them, are brought near together. The tendency that electric charges of opposite sign have to unite, in order to combine and neutralise one another, is opposed by the resistance of the non-conducting medium. The existence of this resistance to the discharge causes a transformation of energy, and changes a portion of the electric energy into heat and light. Hence the spark, in all its varied appearances.

These different appearances we shall now review, distinguishing at the outset, according to Faraday's classification, between the *spark* properly so called, the *brush*, the *glow* and the *dark discharge*. The

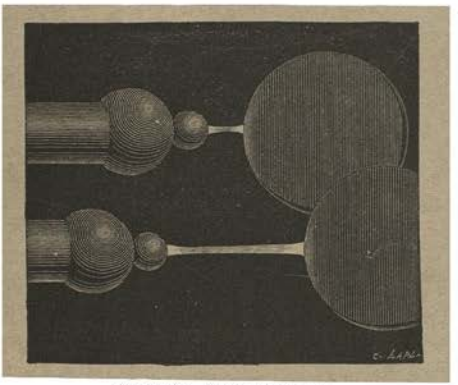

FIG. 282.—Straight sparks.

spark is the luminous line, the flash of fire, which issues between the electrified body, and the conductor brought near to it, and which is usually, as we have seen, in communication with the earth. If only a short distance is allowed for the spark to travel, the spark takes place in a straight, very brilliant line, of uniform brightness, and of nearly the same apparent thickness throughout its whole length. Its size and brilliancy depend on the quantity of electricity which flows, and this in turn depends on the electric capacity and potential of the conductor. If the distance is gently increased, the spark will be lengthened, remaining always a straight line, Fig. 282, but it will be thinner, and will appear larger, and more brilliant at the two ends than in the middle.

If the explosive distance is still increased, and goes beyond two or three inches, the spark often presents an irregular form, sometimes in a continuous zig-zag of straight lines, as in Fig. 283, sometimes offering sinuous, or serpentine ramifications, indicating that the resistance experienced by the flow of electricity in its passage from one conductor to another is very unequally distributed.

Plate VII. represents two curious forms of sparks, observed and copied by Van Marum; the first is fringed with numerous luminous

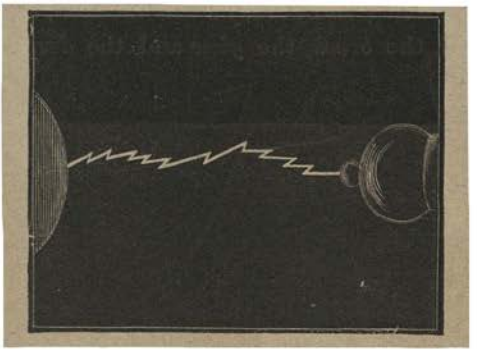

FIG. 283.—Zig-zag spark.

spikes following the general curvature, and which seem to be distributed spirally round the principal luminous furrow; the second, which is much less regular, looks like a main artery, into which run, like so many little rivers, a multitude of luminous branches.

The colour of the light of the sparks is a bluish white in atmospheric air, under normal pressure; a slight purple tint is seen at the extremities. The colour varies with the pressure, and also with the nature of the gas in which it is produced: it is also affected by the nature of the metals used as knobs for procuring the discharge. We will presently give some examples of these modifications.

§ 2.—*The Brush Discharge.*

According as the distance is increased at which the discharge takes place, the more complicated is the appearance of the spark; the flash of fire becomes more and more ramified, weakening towards the end furthest from the conductor, and finishes by transforming itself into a *brush*. The brush is generally composed of a brilliant jet from which spread out diverging threads of a pale violet colour, accompanied by a slight hissing noise like that of a jet of steam. Fig. 286 shows a luminous brush, according to the observation of Van Marum. An easy way to observe the brush discharge is to attach a round-ended wire to the prime-conductor of an electrifying

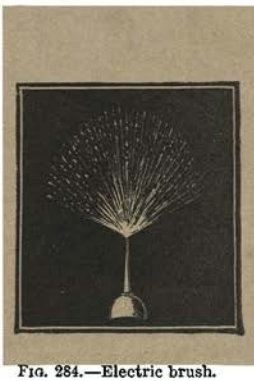

FIG. 284.—Electric brush.

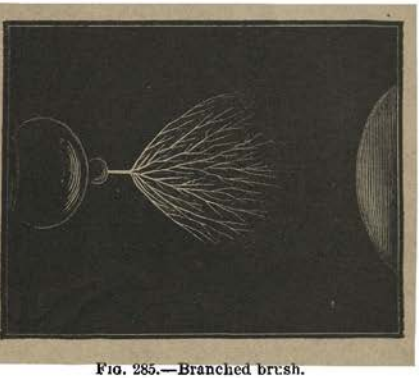

FIG. 285.—Branched brush.

machine (p. 203) and when the latter is at work, hold opposite this, at a few inches' distance, a metal plate. The experiment should be made in a darkened room. Between the plate and the brush sometimes there exists a dark space, sometimes a much narrower mass of light having its base on the edge of the plate. Suppose that the conductor is charged with a positive charge, then the plate will also become electrified negatively by influence. If the conductor had been charged negatively, the large spreading brush would have issued from the plate, and the narrow plume from the conductor. Faraday, who studied the forms of positive and negative brushes, showed that this difference is due to the unequal tendency of the two kinds of

electrification to escape from the surface. A negative charge will more readily discharge itself than an equal positive charge.

Electric luminosities can be produced in different media, in the

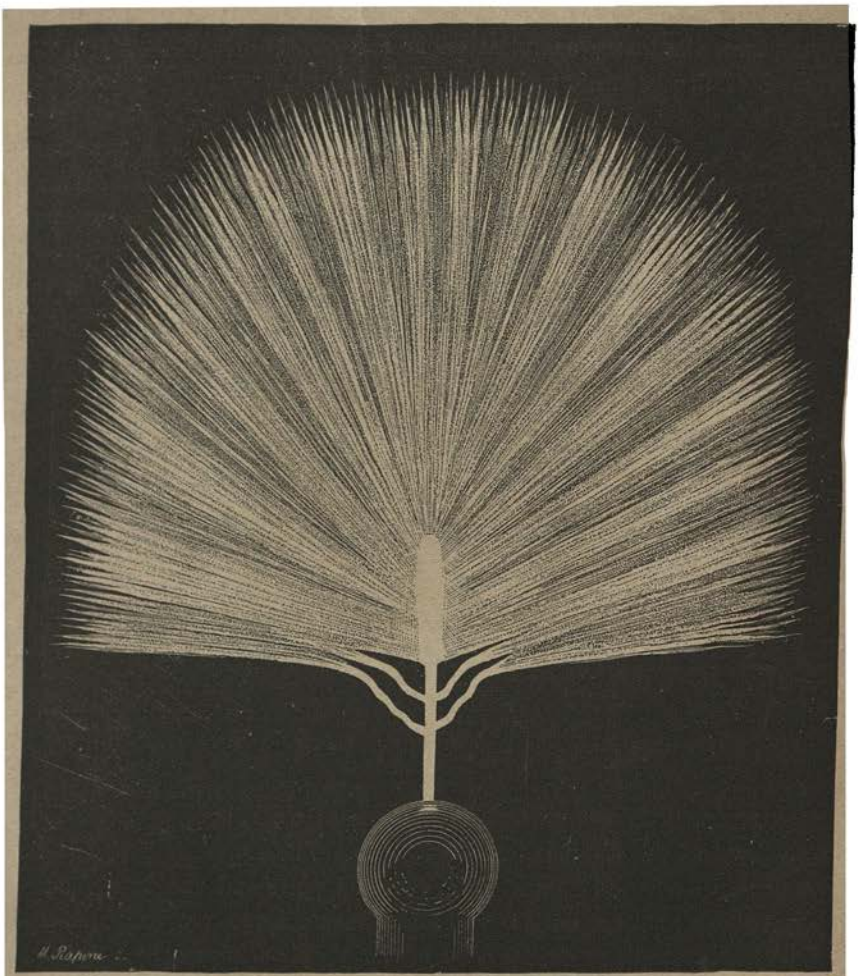

FIG. 286.—Electric brush observed by Van Marum.

air and the other gases, and even in the badly conducting liquids. The appearances it presents, its form and its colour, change according to the media; and when the discharge takes place in gas, they vary with the pressure, or the degree of rarefaction of the gas

In the air at ordinary pressure the spark is as we have seen a brilliant white. According to Van Marum, who made many experiments on this subject, its colour is bluish, tinted with purple, in nitrogen; very white in oxygen; red-violent in hydrogen; greenish in carbonic acid; reddish-green in marsh gas, and white in hydrochloric acid gas.

The body of the luminous positive brushes is, in the air at ordinary pressure, of a violet colour, tinted with purple, whilst the ramifications seem more white, perhaps because there the light is less concentrated. In other gases the colour of the brushes varies, as experiments by Faraday have shown; thus in hydrogen and in coal gas it is slightly green; in oxygen it is white, as in the air, but much less beautiful; in rarefied nitrogen it is on the contrary magni-

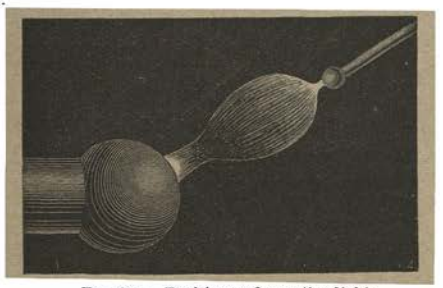

FIG. 287.—Positive and negative light.

ficent, and of a lovely violet hue; in carbonic oxide and carbonic acid it is short, greenish in the former gas, and slightly purple in the latter.

To observe and compare more easily the colours of electric light in different gases one may employ a series of tubes arranged like those of Fig. 288. Into these tubes a, a', a'', filled beforehand with the gases in question, are fixed platinum wires, by means of which they are brought into communication with the outside, and which leave a small space between them in the interior of each tube. On one side the wire is joined to an insulated ball d, on the other b to the earth.

As soon as the ball is put near the electric machine, the spark appears simultaneously inside all the tubes, and you may see at a glance the colour of the flashes of fire in the different gases.

These different forms of electric light, the spark, the glow, and the brush, are separately observed when the old kind of frictional electric machines are used; but by using the induction coil they can be simultaneously obtained. To make the experiment you employ a very powerful induction coil that can give sparks at least eight inches in length. You join the positive electrode of the secondary coil to one of the stems of a pointed discharger, and the negative electrode to the other stem, the end of which you furnish with a metal plate of about six inches in diameter. At a little distance you perceive a glow round the positive pole; the spark is thrown out with its sinuosities or ramifications between the point, and the plate, and at last a feebly luminous brush in the form of a cone envelops the spark and covers a great part of the plate.

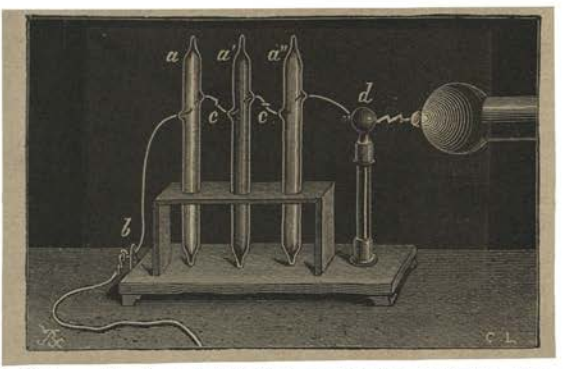

FIG. 288.—Colours of luminous electric discharges in tubes containing various gases.

If you bring the poles nearer together, the brush contracts, the spark increases in size and brilliancy, and finally divides into many branches, Fig. 289. At a less distance than an inch the spark becomes simple, and is surrounded by a larger and more brillant glow or *aureole*. It would seem as if the many luminous tracks were united and condensed into one.

Cazin, from whose writings we borrow these details, showed that a spark, simple in appearance, can be analysed or decomposed. The line of fire is really sometimes formed of brilliant jets succeeding each other by hundreds, at intervals of time which do not last beyond a hundredth of a second each. "An example of this kind of spark, called *composite*," says he, "is furnished by the discharge of Ruhm-

korff's coil, to the poles of which are united wires, on one side to the coatings of a Leyden jar, on the other to two metal balls, between which the spark flies, their distance apart being less than a millimetre. A suitably placed converging lens receives the luminous rays coming from the spark, and directs them in a parallel beam to the edge of a paper disk or 'phenakisticope' spinning rapidly round its centre. The apparatus is placed in a dark room, and you look with a telescope or opera-glass through the opening of the diaphragm.

"When a *simple* spark bursts from the centre of light, you only see in the glass one slit of the turning disk; but when it is *composite*, you perceive the moving slit, which passes behind the opening, in the successive different positions that it occupies at the successive

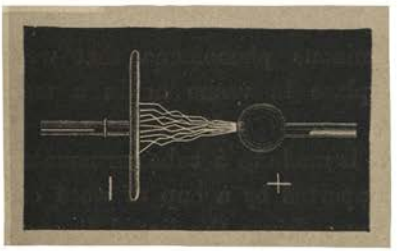

FIG. 289.—Composite electric discharge.

moments when the luminous threads which compose the spark are shot out.

"You then see several bright lines, and their number is the same as the number of the simple sparks which are emitted during the time that one slit of the turning disk has taken to cross the field of the opera-glass. When the number of luminous lines is considerable you cannot count them with the arrangements that have just been pointed out. In that case you cause the slit to pass before the diaphragm more rapidly than the time that the whole spark lasts, and you increase the rapidity of the disk till you perceive in the glass a few brilliant equidistant flashes. You are then certain that the luminous lines succeed each other at equal intervals of time, and it is possible to calculate the total number of these lines.

"With a disk of 180 slits, making thirty-three turns a second, there have been reckoned in an experiment of this kind six brilliant equidistant flashes. From this you deduce that six luminous threads

succeed each other in an interval of time equal to the fraction of a second, $\frac{1}{33 \times 180}$. On the other hand you conclude that the total duration of the composite spark was 0·015 of a second. The number of times the preceding fraction will go into this latter number, will represent the number of times that the six luminous lines are successively repeated in the spark; which gives a total of 537 simple sparks observed in a composite spark." (Cazin, *Journal de Physique*, 1873.)

§ 3.—*Electric Lights in Rarefied Gases.*

Up to the present we have only treated of light obtained by electric discharges in the air, or in some other gas, at ordinary pressure. The luminous phenomena that we next consider are those which take place in vacuo or in a more or less rarefied gaseous medium.

When a vacuum is made in a tube surmounted by a funnel containing mercury, supported by a cup of wood cut perpendicular to the fibres, the pressure drives the liquid through the pores of the wood, and forms the phenomenon known under the name of the *shower of quicksilver*. The brilliant little drops of liquid metal are electrified by their friction against the wooden fibres, and as they fall they emit a tolerably bright bluish light in a dark room. For many years the production of similar lights in the barometric vacuum, when the level of the mercury has been quickly displaced, has been known. We owe to Hauksbee many curious and numerous experiments on the effects of light which are produced in tubes, or glass globes, inside which a vacuum has been made. The interior of these vessels becomes filled with a beautiful purple light, either by shaking up, inside the vacuum, such bodies as wool or mercury, or by making the glass vessel turn rapidly and at the same time rubbing the outside surface. This light is evidently due to the development of electricity.

Later on, Cavendish, and after him Davy, made experiments on the production of electric light in the barometric vacuum, and on the influence that temperature exercises on the brilliancy of this light. The apparatus, Fig. 290, consists of a bent barometric tube

containing columns of mercury in each of its branches, which dip into two mercury cups.

One of the cups had the mercury in it put into communication by a metal wire with the earth, the other with the conductor of an electrifying machine. As soon as the latter is worked, the electricity passes from one cup to the other through the rarefied air in the space between the two columns. You see a feeble bluish light filling this space. By heating the mercury, Davy found the light to increase in brilliancy, and take a greenish tint, which passed to blue,

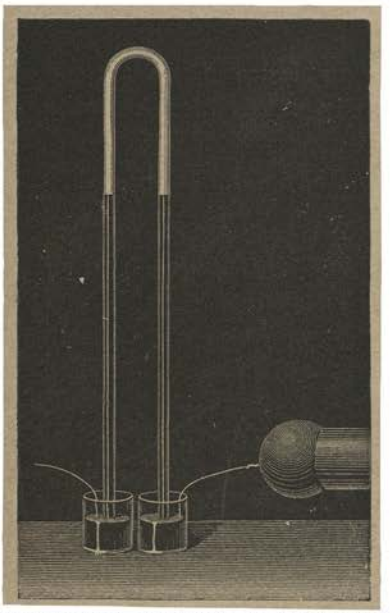

FIG. 290.—Electric luminosity in the vacuum of a double barometer tube.

then to purple by the introduction of some air bubbles. From these experiments Davy thought he might conclude that the feeble greenish light observed at the ordinary temperature was due to the vapour of mercury, since the light was more intense at a higher temperature, that is to say when the production of vapour increased.

The question as to whether an electric light could be produced in an absolute vacuum, was not then settled by these experiments. Mr. J. P. Gassiot, to whom we owe some very interesting experiments on electric light in rarefied gases, has proved that in a sufficiently

perfect vacuum no electric discharge takes place between two wires and no light is produced. Cazin thus describes how Alvergniat repeated in Paris Gassiot's experiment:

"You fuse," he says, "two platinum wires into the ends of a

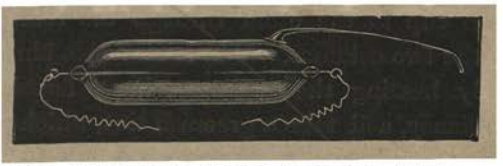

FIG. 291.—Electric discharge refuses to pass in perfect vacuum.

hard glass tube, leaving between them a space of one or two millimetres. This tube Fig. 291, is furnished with a side tube, that is

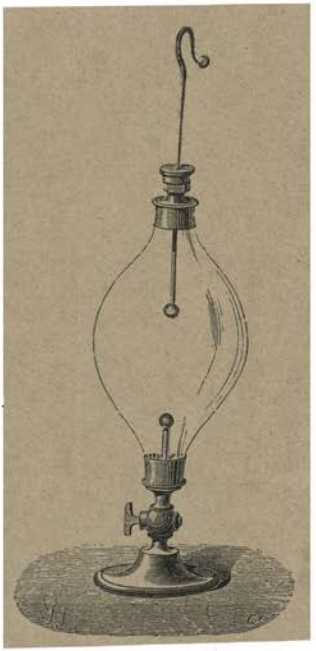

FIG. 292.—The electric egg.

afterwards fused to the tube of a mercurial air-pump. Having made the vacuum for the first time, you heat the glass tube to a dull red, and you work the pump for some time longer in order to take away all traces of air or vapour that might adhere to the interior sides of the

tube and the platinum wires. If, after working it for an hour or more, you connect the platinum wires to the conductors of an induction coil you see no spark between the wires, you then separate the tube from the pump by fusing off the lateral tube in the blow-pipe flame; the apparatus thus closed hermetically by fusion serves to repeat the experiment indefinitely."

To study the luminous effects which the electric discharge

FIG. 293.—Electric-discharge in rarefied air, showing purple bands.

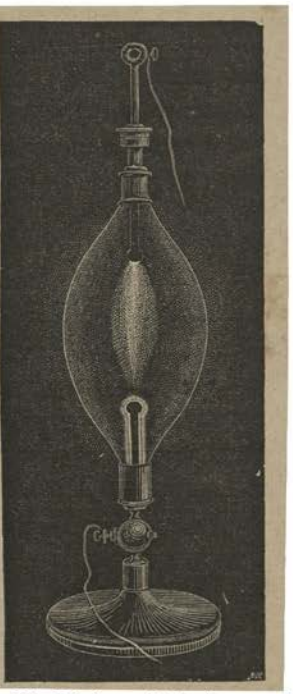

FIG. 294.—Discharge of induction currents in highly rarefied air.

produces in rarefied gases, one may employ the apparatus represented in Fig. 292, which is called from its shape the *electric egg*. The two metal rods, each terminated by a ball, can be brought together or separated at will. The egg can be separated from its stand, and screwed on to the air-pump, so that you can there rarefy the air at pleasure, make the vacuum, and then introduce any gas at any pressure.

When the egg contains simply air at ordinary pressure the spark

passes between the two balls, as we have described above. But as the air becomes rarefied, the light changes in appearance: it starts like a branched sheaf from the positive ball; at the pressure of sixty millimetres it presents the aspect shown in Fig. 293. You see then that it is composed of a certain number of luminous bands of a purple colour, some diverging laterally, others ending at the negative ball, which is itself enveloped in a thick layer of violet light. When the pressure is reduced some millimetres the bands unite into a luminous sheaf in the form of a spindle, and the purple light around the negative pole becomes more brilliant and thicker. We shall now see what happens when you substitute induction currents for electricity of the ordinary frictional electric machines.

Rarefy the air contained in the electric egg to the pressure of two or three millimetres of mercury, and put the balls inside in communication with the poles of a Ruhmkorff coil. We shall immediately see a magnificent luminous sheaf of a red tint issue from the positive ball, whilst the negative ball and rod are enveloped in a layer of light of bluish purple (Fig. 294). If you reverse the direction of the current by means of the commutator, immediately the two lights are inverted; the sheaf will then come from the lower ball, whilst the violet mantle will envelope the upper one. On close examination it will be noticed that the violet mantle of light around the negative pole appears not to touch the metal beneath it; there is a narrow dark space between.

§ 4.—*Striæ.*

If before rarefying the air you introduce the vapours of certain substances, for example, alcohol, phosphorus, the essence of turpentine, the luminous sheaf takes a peculiar aspect, which was discovered almost at the same time by several observers. The red light of the sheaf is interrupted transversely by dark bands lying very close together, so that it is formed alternately of dark and brillant lines. From the middle of the sheaf where the bands are straight they curve in two opposite directions, so that they inclose the ball in their concavity. To this phenomenon is given the name of *striæ*, or stratifications.

Different forms have been given to the tubes or glass vessels containing rarefied vapours suitable for the production of striæ. The late Dr. H. Geissler, of Bonn, devised a number of most curious and beautiful apparatus to show experiments of this kind; his tubes are known under the name of *Geissler's tubes*. The beauty of these luminous effects is again increased by the phenomena which this light produces with uranium glass, with the sulphides of strontium and

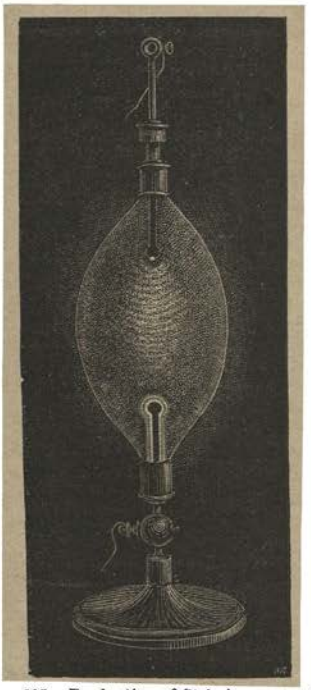

FIG 295.—Production of *Striæ* in vacuous bulb.

calcium, and with sulphate of quinine. The pale light of the electric discharge in rarefied gases appears to be particularly rich in those rays that are effective in evoking the phenomena of phosphorescence and fluorescence in these substances. The brilliant phenomena that we have just mentioned under the name of striæ were observed for the first time by Abria in 1843. Having discharged an induction coil through a tube which inclosed air at a pressure of two millimetres he obtained a brush issuing from the positive pole, not going quite up to the negative pole, from which it

remained separated, as we saw before, by a dark space (Faraday's "dark discharge"). Further, this brush presented at the upper part, that is to say, the nearest part to the negative pole, alternate luminous and dark zones. These are the striæ that, towards 1852, Grove in England, and Quet in France, studied almost at the same time, and which have been the objects since of many interesting researches on the part of many physicists—Gassiot, De la Rive, De la Rue and Müller, Spottiswoode, Crookes, and others. We will say a few words about them.

Quet having observed that the bands appeared sometimes animated by an undulatory and progressive movement, found that this was only an illusion, due to the fact that brilliant zones vary

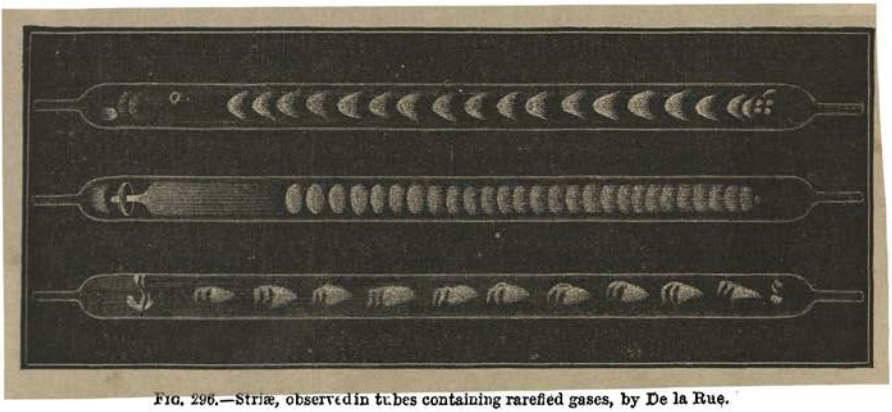

FIG. 296.—Striæ, observed in tubes containing rarefied gases, by De la Rue.

continually, caused by the irregularities in the interruption of the discharges. In truth, the light is completely discontinuous, formed of brilliant layers, which are separated very clearly by the dark spaces between. To give to the phenomenon all its brilliancy Quet mixed with the air in the electric egg, before making the vacuum, the vapour either of wood-spirit, of essence of turpentine, oil of naphtha, alcohol, bisulphide of carbon, or of fluoride of silicium. Brilliant effects of stratified light have also been obtained with metallic vapours, notably that of sodium.

The lights from the two poles are both stratified.

According to Warren de la Rue all the stratifications have their origin at the positive pole. With a given tube and a certain gas there is a pressure for which you obtain a simple light, which is

formed at the positive pole; when you gradually diminish the pressure this light becomes detached, moves towards the negative pole, and is successively followed by several others, the number of which increases gradually up to a certain limit.

On putting nearer together the two balls in the egg Quet found that the negative pole alone remained illumined, and that the dark space which separated the strata of the two poles reached right across to the positive pole.

In the vacuum made with vapour of fluoride of silicium, he saw the violet light of the positive pole disappear, and at the same time the yellow light of the negative pole revive; on bringing the poles nearer still the negative light became feeble, and purple rings formed on the positive ball. Warren de la Rue proved that a change of strength of the current often produced a complete modification in the colours of the striæ; for example, in a tube with hydrogen they pass from blue to rosy crimson.

Phenomena of stratification were originally observed only in the discharges produced by the aid of induction currents; but Van der Willigen obtained them with a Leyden jar, only it was necessary to interpose a suitable resistance, for example a moist thread, into the circuit to retard the discharge. Quet and Seguin obtained the same result in weakening the charge of the jar; by covering the outside surface of Geissler tube with tin foil, so as to transform it into a condenser, and making it communicate with the earth, they produced in the tube a veritable wave of stratified light, by the discharge of a frictional plate machine. Lastly, Gassiot, employing a water-battery of 3,520 well-insulated cells, or a battery of 400 of Grove's cells, obtained striæ in a tube of rarefied carbonic acid gas.

Various hypotheses have been proposed to explain the phenomena of striæ. Grove considered the sparks from an induction coil as formed by a rapid succession of partial discharges, and regarded the stratifications as the result of a sort of interference between successive and contrary discharges, establishing thus an analogy between these phenomena and the interference bands obtained with luminous or sonorous waves.

But, as Mascart has observed, it is not easy to conceive how interferences between two systems of discharge can be produced where they are not simultaneous, but alternate, and if these two

currents interfere in the phenomenon the mechanism of the production of strata presents no analogy with the interferences of light and sound.

Other physicists, like Gaugain and Reutlinger, regard the striæ as produced by chemical actions, combustion, simultaneous combinations and decompositions. De la Rive says "the phenomenon may consist in alternate contractions and expansions of the gaseous medium produced by the series of discharges, always more or less discordant, of which the electric jet is formed."

According to this view striæ would be a phenomenon analogous to that of sound-waves.

This is a hypothesis which resembles that of Grove and also that of Gassiot. May not the dark bands, asks Gassiot, be the nodes of undulations arising from impulses proceeding from positive and negative discharges; or can the luminous stratifications which we obtain in the closed circuit of the secondary coil of an induction apparatus, and in the circuit of the voltaic battery, be the representations of pulsations which pass along the wires of the former, and through the battery of the latter—impulses probably generated by the action of the discharge along the wires?

We will conclude by giving the explanation of the phenomenon which Quet and Seguin have framed; an explanation based on the mode of propagation of electricity, a propagation which does not take place by a movement of transport of electricity itself, but, according to these thinkers, by a movement of successive decompositions and recompositions.

The phenomenon of sparkling tubes (p. 227) serves then as a term of comparison. "When electricity arrives on the metal conductors of the electric egg, the column of rarefied gas divides into successive layers, some of which play the *rôle* of the little metal plates of a sparkling tube, and others that of layers of air in which the sparks of these tubes burst forth. In the former layers the two electric fluids, which are there developed by influence, tend, the one towards the positive ball, the other on the opposite side. The highly mobile molecules of gas there receive contrary movements rarefying some of these layers and condensing others. These latter, which separate the opposite charges of electricities, become heated and illuminated when a discharge takes place, whilst the

rarefied layers (which, consequently, are the best conductors,) remain dark." By means of this theory Quet and Seguin have succeeded in rendering an account of all the appearances presented by the striæ. Besides, they have been able to imitate this phenomenon in several ways. Thus, after having shaken some carbon dust near the discharging wires they caused an induction spark to pass into the air, and they saw that this spark became stratified transversely, taking a considerable length; it was like a long string of luminous beads. This effect is produced also in a sooty flame, and even in the dark part of a candle-flame. At the top of a flame of the spirit of turpentine the brilliant points are replaced by little distinct flames.

[The phenomenon of the "dark space" has been studied during late years by Crookes, using perfected mercurial air-pumps, by means of which much more perfect vacua could be attained. He found that with very high exhaustion the dark space that exists between the

FIG. 297.—Stratification of carbon dust produced by the induction spark.

negative pole and the violet layer of light that surrounds it grew wider, and finally, with still higher exhaustion, extended right across the tubes. He then observed that there appeared to be a steady flight of molecules sent off from the negative pole, normally to its surface: and he found that this negative discharge could exercise a mechanical force upon objects placed in its path, and could push them away from the negative pole. He caused small poised vanes of mica to rotate in the molecular stream. He further found that these streams of molecules, when they beat against the opposite glass walls of the tube, produced a curious phosphorescence, and that if objects cut out in mica were interposed they cast molecular shadows upon the phosphorescent surface. The streams of repelled molecules were also found to be acted upon and drawn on one side by a magnet. In short, Mr. Crookes found the properties of the highly rarefied gases in this state to be so different from those of ordinary gases that he was driven to consider them as being in an ultra-gaseous state,

more different from ordinary gas than ordinary gas is from liquid. To this fourth state of matter he gave the name of "radiant matter."

More recently still Schuster has found that many of the phenomena of discharge in gases resemble those of electrolysis in liquids, the phenomena of discharge being accompanied by a breaking up of the molecules into atoms. Using as the gas the vapour of mercury, which is known to have only single atoms, not pairs of atoms, for its molecules, he found the phenomena of discharge to be quite different from and much simpler than those obtained with any other gas.]

§ 5.—*The Voltaic Arc.*

The ordinary voltaic batteries used to produce currents have comparatively small electromotive forces. For example, a battery of fifty Groves's cells has an electromotive force of only ninety-seven volts. Now it is known that the electromotive force required to cause a spark to leap through a layer of air only one-hundredth of an inch in thickness requires at least two thousand volts. We find, in fact, that if we take the two wires coming from the poles of any ordinary voltaic battery, and gradually bring them together, no spark will leap across until they are actually made to touch. But it is also found that if the wires are once made to touch, and then are parted, a spark will show itself just as they part. This is due to the extra-current (p. 381), and it causes a small portion of the end of the wire to be torn off and volatilized. In 1800 Davy found that the sparks were more brilliant if dense charcoal points were used to take the spark. Four years later, using a more powerful battery, he observed that if charcoal points were employed, and were first made to touch and then separated to a short distance—about the twentieth of an inch—a brilliant light was given by the spark, and that there appeared between the white-hot charcoal points a sort of *flame*, which continued to play across, and formed a conducting bridge by which the current could flow. To this persistent spark or flame he gave the name of the *voltaic arc*. With a more powerful battery a much longer flame or arc could be maintained.

The name voltaic "arc" is due to the circumstance that originally the charcoal points were put on a horizontal line; the ascending movement of the heated air caused the luminous line which issued between the electrodes to curve upwards. This curvature no longer exists when you place the charcoal points vertically; but the original name has continued to be employed, though the appearance of the phenomenon ceases to justify it. A year or two later, by the help of a battery of 2000 cells, each of which had 60 square inches of surface, Davy obtained a dazzling light, which streamed continuously across the space between the two charcoal points. When once the discharge had been obtained by parting the charcoal points it was found that with this enormous battery the arc could be extended to the length of four inches between the points. The appearance presented was then one of extraordinary brilliance. The electric discharge extended between the two electrodes in the form of an arch, with its convex side up, and of such intense brilliancy that the eye could scarcely support the light. In a partial vacuum the length of the arc is greater than in the air.

Since Davy's time the production of the voltaic arc has been rendered easier, partly by the invention of the magneto-electric and dynamo-electric machines, which we have described in the preceding chapter, and also partly by reason of the substitution of coke-carbon for wood charcoal, such as Davy employed.

Davy made use of slips of boxwood charcoal extinguished in water or in mercury. To Foucault is due the use of hard gas coke, which is denser, more homogeneous, and a better conductor. He sawed it up into long pencils two or three millimetres square; since then methods have been invented for purifying the carbon, or replacing it by different combinations or mixtures. We shall speak hereafter of the substances adopted by the inventors of the different systems of electric lighting. When hard carbon is used, the arc itself is found to give out but little light, but the tips of the carbon pencils glow with an overpowering white light: they are in fact brilliantly white hot. The relative non-luminosity of the flame or arc itself arises from the fact that it consists not of solid matter, but of vapour.

The arc, however, is intensely hot; in it metals melt like wax in the flame of a lamp. The most refractory bodies have been melted and volatilized by Despretz, first by the aid of a battery of 600 cells, then

by the use of a magneto-electric machine. The oxides of zinc and iron, calcium, magnesium, aluminium, were reduced to globules. Graphite volatilized in the arc deposited on the electrodes a dust, which, when examined by the microscope, was recognized as being formed of very small crystals of octahedral form; with this powder rubies may be polished, whence it is concluded that graphite, which, like the diamond, is nearly pure carbon, was crystallized under the influence of the intense heat of the arc, and transformed into very minute diamonds.

Davy, when experimenting with the arc in rarefied air, obtained with his powerful battery of 2000 cells, a jet of light seven inches long.

The luminous intensity of the voltaic arc is so considerable that the eye can scarcely bear its brilliancy. According to the measurements made by Fizeau and Foucault, this intensity is nearly fifty times that of the light obtained by directing a flame of oxyhydrogen gas on to a fragment of lime. These two savants worked with a Bunsen battery of cells, arranged in two series. Even solar light is only three times as intense as the voltaic arc. It should be clearly understood that their comparison relates to the intrinsic brilliancy per unit of surface; not to the total amount of light evolved. We shall see in the applications of electric light to illumination what is the illuminating power of the voltaic arc.

The length of the arc, as Despretz has remarked, depends on the number of cells of the battery, and their arrangement. Having employed batteries of 50, 100, 200, and 600 cells, the length of the arc obtained was found to increase at first from one to four; but this proportion did not continue; the arc given by 200 cells, was scarcely three times that of 100, and that of 600 was only seven or eight times longer.

By watching closely the voltaic arc, it has been noticed that the current of electricity which passes continuously between two points carries with it small particles of carbon, which it tears away from the tip of the positive pencil and deposits on the negative core. In addition to this transport of matter both the tips slowly burn away, so that the carbons are used up at unequal rates. The negative carbon is worn away to a point, whilst the tip of the positive carbon is hollowed away and presents the appearance of a luminous *crater*.

Fig. 298 shows the appearance of the two points seen by projection and enlargement through a lens. Le Roux, to whom this drawing is due, thus describes the appearance. The quotation is from a lecture on the application of electricity to lighting lighthouses.

FIG. 298.—The voltaic arc, and the tips of the carbon pencils.

"In examining directly that which goes on in the voltaic arc, great precautions must be taken to guard the organs of sight against the great brilliancy of the light; but this same brilliancy permits us to examine all the little details of the surface of the carbons. All that is necessary is to interpose between the carbons and the white screen a lens of suitable focus. Projected on the screen you see the

image of the points magnified a hundredfold; this method allows you to examine without fatigue the whole of the phenomena. Here, Fig. 298, are the carbons between which a continuous current from a Bunsen's battery passes: you see one of the carbons increases at the expense of the other; the one the most used is the positive carbon; it is the one that communicates with the positive (carbon) pole of the battery. If it is less pointed than the other, it is because it loses matter while the other gains it. We will now reverse the current; you then see the carbon which just before was the most pointed grows blunt, whilst the other becomes pointed; moreover from time to time some bigger particles are detached, traversing the space in the form of little incandescent masses, and show well the direction of the transfer. You see little globules boil up here and there, at the surface of the points; these are globules of molten silica. You will notice that these globules do not appear at the points of the carbons, where the temperature is the highest: they are volatilized before the intense heat of the white hot tips. Now we come to a very impure vein, where too many of these globules of silica show themselves; the brilliancy of the arc becomes enfeebled and if you blow gently across the points, the current of air bends the flame, and shows its structure. Now we reach a part of the carbons where their purity seems to leave nothing to be desired. You see how steady the arc is, the consumption is regular, the surfaces well defined. You see the soft blue light of the arc contrasting with the brilliant white of certain parts of the carbons. The arc forms a sort of truncated cone swelling out in the middle, the two bases of which are on the carbons: at these two bases are the most brilliant parts; it is there that the temperature is the highest, it is there that the molecules carried across by the current strike."

It is partly because of this transport of particles from one pole to another in the arc, and partly because of the volatilization of the carbon itself that you are able, when once the arc has been "struck," to separate the points to some distance apart. If a very soft carbon, such as a carbonised piece of lamp wick is employed, so many particles are torn off and carried into the flame that the whole arc becomes luminous.

The length of the arc, as we have before seen, depends on the electromotive force that is applied; it depends also on the substance

of the pencils that serve as the electrodes. The most fusible bodies, and those having the least tenacity, give the longest arcs. According to Grove, metals may be ranged, in this point of view, in the following order, beginning with those which give the longest and the most brilliant arcs: potassium, sodium, zinc, mercury, iron, tin, lead, antimony, bismuth, copper, silver, gold, platinum.

§ 6.—*Magnetic Action on Luminous Electric Discharges.*

An interesting experiment, described above, has shown us the influence of the magnet on the light of the voltaic arc. You may obtain an analogous effect by operating on induction sparks, for example on those which are obtained with a Ruhmkorff coil. Fig.

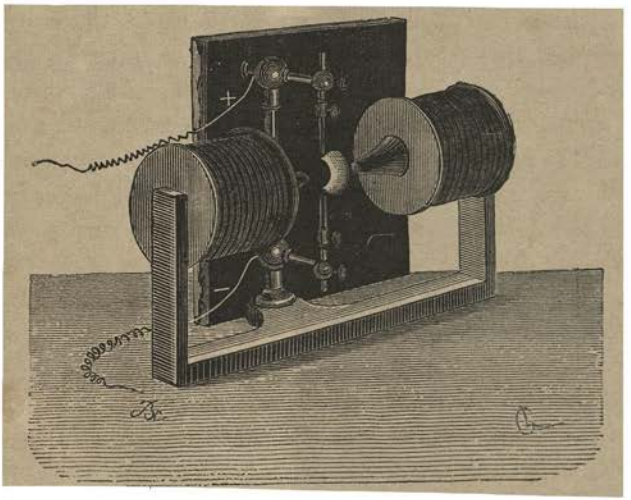

FIG. 299.—Action of the magnetic field upon the spark of an induction-coil.

299 shows how this experiment is arranged. As soon as the electro-magnet is excited, the spark that issues from between the two poles takes the form of a luminous sheet, in form of a semicircle, from the edge of which issue, like so many rays, a number of streaks of fire. The sheet bends across between the poles, as if urged by a force tending to drive it sideways out of the magnetic field; but its curvature is reversed if you change the direction of the current of

the induction coil; it is also reversed if you change the direction of the current which excites the electromagnet. The discharge in fact

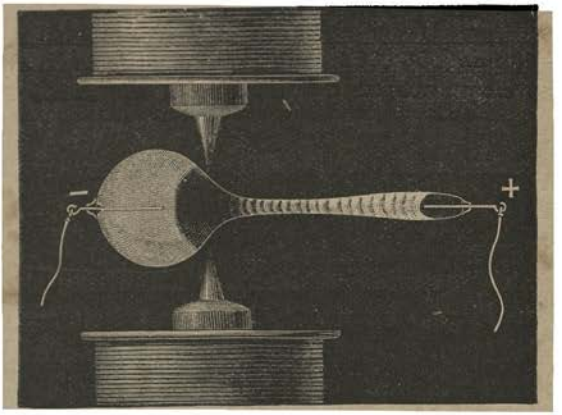

FIG. 300.—Action of a powerful magnet on the luminous discharge in a vacuum-tube.

follows the same law as is obeyed by a conducting wire carrying a current when acted upon by the magnetic field.

We owe to Plücker, Gassiot, and to De la Rive, some interesting researches on this influence of magnets upon the aspect of the

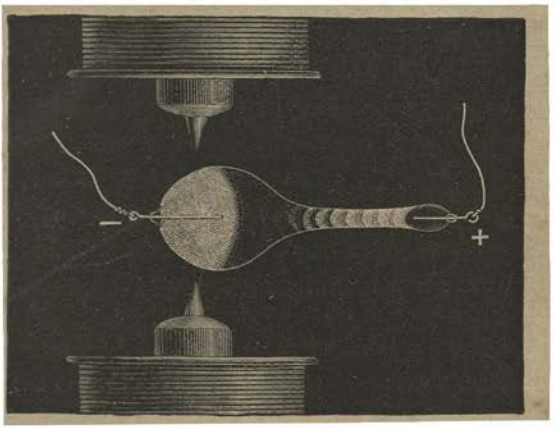

FIG. 301.—Action of powerful magnet on the luminous discharge in a vacuum-tube.

different kinds of electric lights. Figs. 300, 301, and 302 depict the modifications which the light from the negative pole of a Geissler

tube undergoes when it is placed between the poles of an electromagnet. The violet light that fills the tube round the negative electrode is transformed into a thin flat layer as soon as the electromagnet is excited. The form and the position of the dark space separating this light from the stratifications of the positive pole change according as the negative pole is to the right or left of the line joining the poles of the electromagnet; and it also varies according as the direction of the tube is perpendicular or parallel to this line.

Plücker, in the experiments that we have mentioned, had remarked that magnetic action determined changes in the colour of the light in the tubes. This latter phenomenon has been the object of the studies of Trèves, who employed vacuum-tubes having the middle part made of a capillary tube. He placed this part between

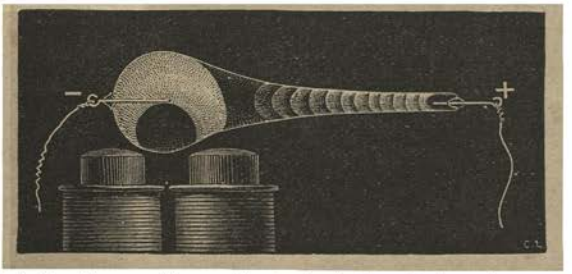

FIG. 302.—Action of a powerful magnet upon the luminous discharge in a vacuum-tube.

the conical poles of an electromagnet, in a direction perpendicular to the line of the poles, Fig. 303. As soon as the current passed, and excited the electromagnet, the colour of the light in the tube was changed; these changes were also characteristic of the nature of the rarefied gas. If the tube contained hydrogen—in which case the light is violet at the poles and red in the capillary part—the red disappeared to give place to a white light.

Oxygen gives an exactly inverse effect—the white light passes to red; in nitrogen the change is from pale blue to dark blue; and in carbonic acid from white to blue. In a tube of fluoride of silicon the ends are greenish, the capillary part is blueish: magnetism renders the latter a violet blue. In a tube of bromine the colour changes from violet to blue; and in a tube of chlorine from bluish white to deep blue.

What is the cause of this influence of magnetism on the light of induction currents and on electric light in general? This is a theoretical point which has not yet been elucidated. All that one can say is that rarefied gases are subject, whether they are true conductors or not, to the laws that govern conductors; but the phenomena are yet very obscure. De la Rive has attempted to elucidate this point by various experiments, in the course of which he discovered the rotation of the spark by a magnet. The apparatus which Fig. 304 represents is that used by this celebrated experimenter. It consists of an electric egg, inside which is placed a rod

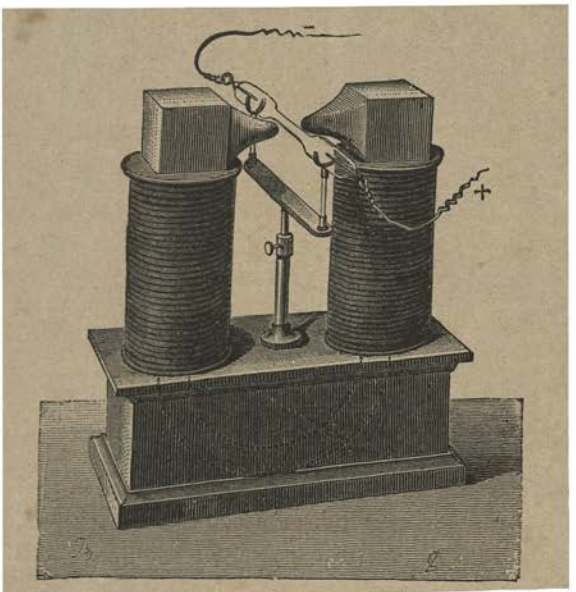

FIG. 303.—Change in colour of luminous discharge under the influence of a magnet.

of soft iron, A C, part of which extends outside; the side surfaces of the rod within the "egg" are covered with a thick layer of shellac; its lower end is inserted in a magnetising coil of wire E. The lower end of the "egg" is cemented into a metal collar through which the iron core passes. When the air in the electric egg, mixed with a small quantity of ether vapour, has been sufficiently rarefied by means of an air-pump, you pass into it by the aid of wires R and R′ the current from an induction coil. A luminous arc is thrown out between the summit C of the cylinder of iron and the metal collar,

which itself communicates with the wire R. This luminous arc is formed of one or more curved sparks or lines of light. As soon as the current from the battery, supplied through the wires P P′, flows round the coil E it magnetises the iron core, and the luminous arc is observed to begin slowly revolving round the upper part of the core The direction of rotation is in conformity with Ampère's laws; it

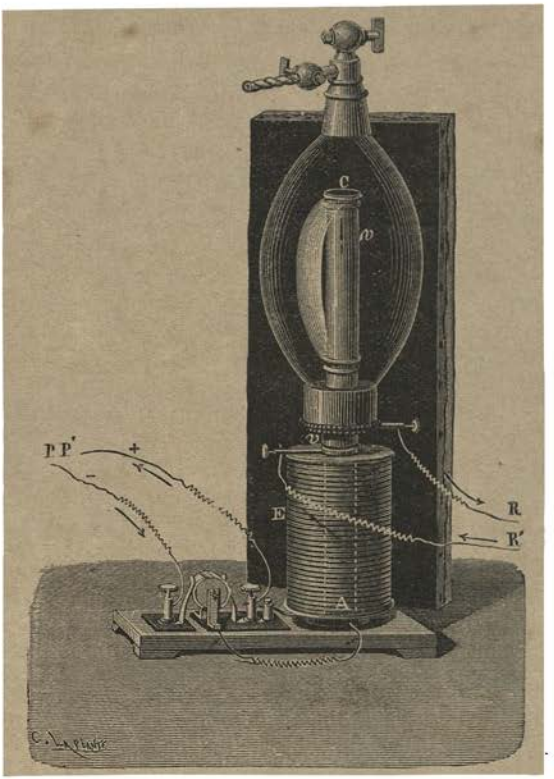

FIG. 304.—Rotation of the luminous electric discharge around the pole of a magnet.

changes when you change the direction of the induced current, or when you invert the polarity of the electromagnet by turning the commutator.

In recent years Crookes has made many experiments on the action of the magnet upon the discharge from the negative pole of vacuum tubes; and he has used more perfect vacua than any of the previous experimenters.

§ 7.—*Luminous Phenomena of Secondary Currents.*

We shall complete what we had to say of the luminous effects of electricity by the description of some phenomena which have been obtained by applying very great electromotive forces such as can be obtained by employing secondary batteries and the rheostatic machine. It is from the inventor of this apparatus, Gaston Planté, that we borrow most of our description.

The current of twenty secondary batteries, each one composed of forty small accumulator cells, was caused to pass through water by means of a pair of platinum electrodes, when the following phenomena were observed :—The positive electrode being plunged before-

FIG. 305.—Globular discharge from secondary battery.

hand into distilled water, one obtains, on bringing the negative wire to the surface of the water and lifting it up immediately, a yellow flame, almost spherical, of about 2 centimetres in diameter. The platinum wire, 2 millimetres in diameter, melts quickly, and remains in fusion at a height of 14 or 15 millimetres above the liquid. This flame is formed by rarefied incandescent air, by the vapour of the metal of the electrode, and by the elements of the vapour of decomposed water; spectrum analysis shows clearly the presence in it of hydrogen gas.

If, to avoid the fusion of the metal, you diminish the intensity of the current by interposing in the circuit a liquid resistance, consisting of a column of water, the spark appears under the form of a clear little globe of fire from 8 to 10 millimetres in diameter (Fig. 305). On lifting the electrode a little, this globe takes an oval form; blue

luminous points, the number of which varies continually, arranged in concentric circles, appear on the surface of the water (Fig. 306, i.). Rays of the same colour soon appear in the centre with their points joined (Fig. 306, ii.). At intervals the rays take a twirling movement, sometimes in one direction, sometimes in another, describing spirals (Fig. 306, iii., iv.). Sometimes the points and rays disappear all on one side, and various curves, formed by the movement of those which remain, appear on the surface of the liquid. Finally, when the quickness of the twirling movement increases, all the rays vanish, and you see nothing but blue concentric rings (Fig. 306, v.). The rings are the last of these transformations, which are very curious to follow with

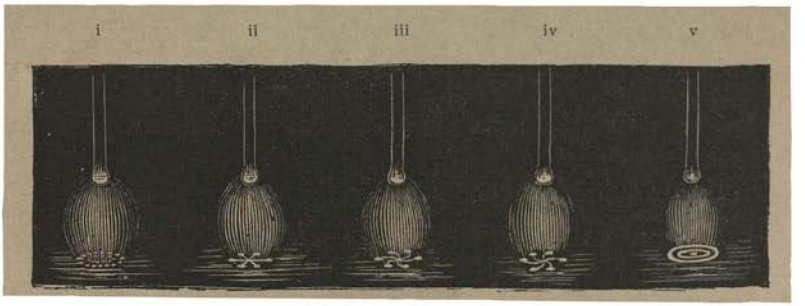

FIG. 306.—Globular flames and luminous rings obtained by Gaston Planté when experimenting with secondary batteries.

the naked eye, or with a glass, and constitute a veritable *electric kaleidoscope.*

"The production of these figures," adds Planté, "is explained by the great mobility of the arcs or luminous bands which compose the egg-shaped light formed between the water and the electrode. In examining with care this particular form of the spark, you see that it is in reality a kind of tuft or voltaic *aigrette,* analogous to brush discharges of static electricity, but denser, because of the much greater quantity of electricity at work. These luminous bands being in a state of continual agitation, the points where they meet the surface of the liquid change places constantly, and form the rays that are observed. Their twirling movement comes from the reaction due to the spreading out of the stream-lines of the current. As for the rings, they are formed in a visible manner under the eye of the observer, by the continually increasing rapidity of the movement of

the blue points, and by the persistance of the impression on the retina of the eye."—(Gaston Planté: *Recherches sur l'Électricité.*)

The discharges of the rheostatic machine (p. 323) produce luminous effects analogous to those which electric machines and induction coils give, but present also some interesting peculiarities.

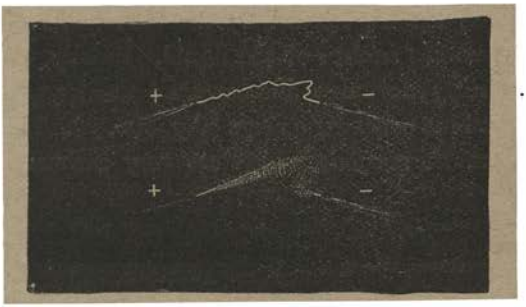

FIG. 307.—Sparks and brushes of hooked form, obtained from Planté's rheostatic machine.

Thus the spark has a special form when the branches of the discharger between which it issues, form a very obtune angle. This form consists in a streak of fire beginning in a straight line in the prolongation of the positive branch, rising considerably above the negative point, and rejoining it by a hook-like curve, forming numerous sinuosities at this part (Fig. 307). The same form is found in the brush which this

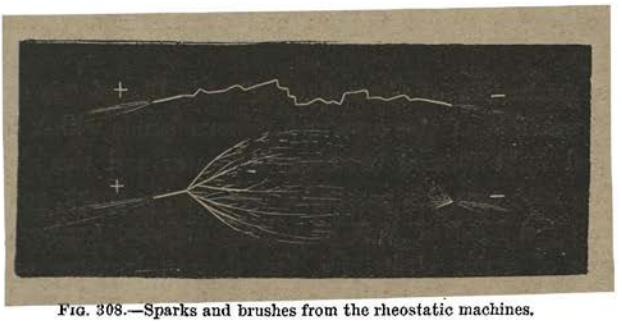

FIG. 308.—Sparks and brushes from the rheostatic machines.

machine gives, when you increase the distance of the points by 1 or 2 millimetres. A conical luminous jet thrown from the positive pole, traverses about three-quarters of the distance to the negative pole and curves towards the short brush formed round the negative point (Fig. 307). Planté attributes this difference of form to the fact that

the rheostatic machine does not, like induction coils, give a flow of electricity alternately positive and negative, but furnishes a discharge that is always in the same direction. With machines having from

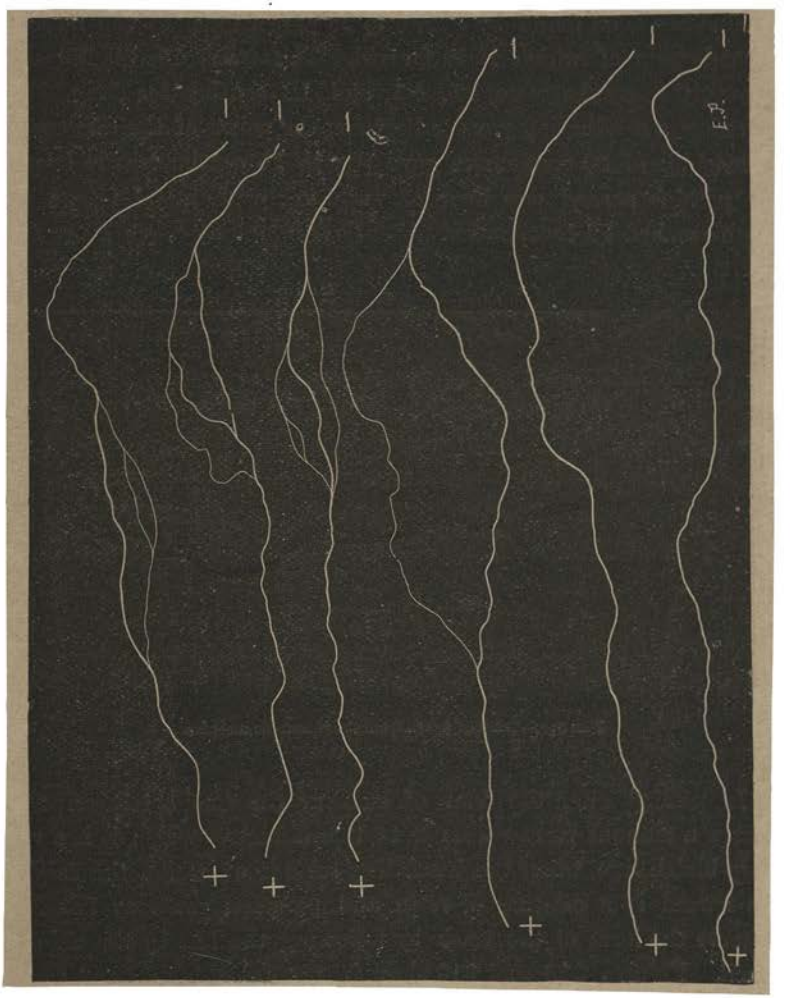

FIG. 309.—Sinuous sparks from the rheostatic machine.

thirty to fifty condensers, the sparks reach the length of 4 to 5 centimetres, but they are less continuous and their form less constant; their sinuosities rise or fall irregularly above or below the straight line joining the two points of the discharger (Fig. 308). The brushes which

appear at the positive pole have an ovate and ramified form, in the main similar to those we have already described in the discharges given by ordinary frictional electric machines.

The length of the sparks produced in the air by the rheostatic machine has been found by Planté to be proportional to the number of condensers of which it is formed. Thus with 10, 30, 80 condensers, the sparks were 1·5, 4·5, and 12 centimetres long. On spreading a conducting powder between the points of the discharger, the machine of 80 condensers gave sparks 15 centimetres in length. The powder spread was flour of sulphur: with metal filings the length reached 70 centimetres.

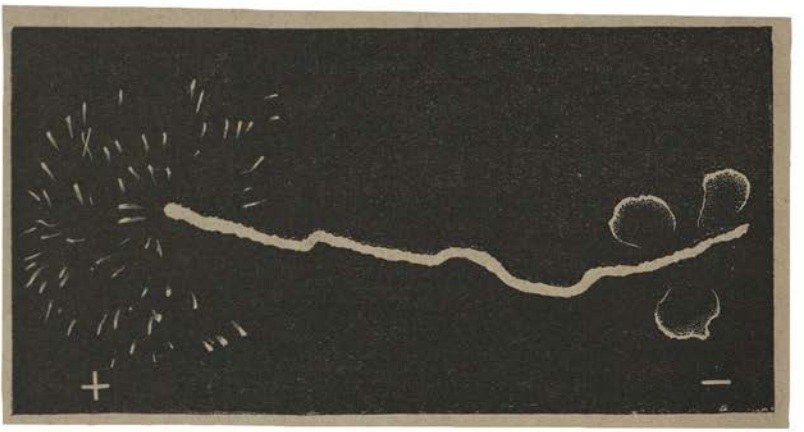

FIG. 310.—Track of spark from the rheostatic machine.

In passing over the flour of sulphur the sparks left on their passage a sinuous furrow from 2 to 3 millimetres wide: it is a very sharp bluish line, when the insulating surface on which the sulphur was spread is a mixture of resin and paraffin; you may faithfully preserve the form of the track by following the line by the aid of a pencil. Figures 309 and 310 show in natural size different sparks obtained in this way. Some, particularly those which do not reach the greatest length, exhibit branches like the anastomoses of arteries, or like the branches of a stream where the course divides to form islands.

If you gently shake the insulating plate on which the flour of sulphur has been spread, and on which, as we have said, the sparks

FIG. 311.—Arborisation, or tree-like pattern left by the electric discharge.

have left their trace, you will find that some of the sulphur remains behind in a curious pattern with numerous tree-like branches, showing how, in the discharge, the electricity is distributed. Fig. 311 shows in natural size the tree-like branches formed on the path of a spark of 15 centimetres in length produced by the rheostatic machine.

"These effects," says Planté, "afford an explanation of the tree-like impressions that have been sometimes observed on the bodies of persons struck by lightning, and which are only the result of the ramifications of the track of the lightning itself." Here is a recent example of these singular traces of lightning which Planté has taken from *The Lancet*. A shepherd in the county of Leicester was keeping his sheep in the fields, when a storm burst overhead, and naturally, as many people are stupid enough to do, he sought refuge under a tree. A little while after he felt a shock in his left shoulder, and losing entirely the use of his legs, he fell. When he was carried home he was still conscious, and complained of pain in his back and legs. The examination made by the doctor who was called to his assistance showed a very curious effect of the lightning stroke. From the left shoulder downwards over the whole back there appeared admirably produced in relief on the skin, and in a brilliant scarlet colour, a stem of a tree with numerous branches delicately traced as if with the point of a needle. The stem was nearly three-quarters of an inch in width, and the general look of it was like a stem of fern with six or eight branches. The whole was wonderfully well reproduced and imprinted on the patient's back. It is easy to render an account, adds Planté, of this case by its analogy with what occurs in the preceding experiment. At the moment when the spark is produced you see the flour of sulphur projected into the air, particularly round the two poles. So also in the case of the fall of a thunderbolt, the dust of the soil, or of any other matter placed on the passage of the discharge, would be projected, and one may conceive that this matter, having been brought to a high degree of temperature, might produce on the human body an effect of instantaneous cauterisation in an arborescent form. In Fig. 310, the traces of the spark are such as they appear on the powdered plate before the loose powder is shaken off to let the arborisations be seen. The furrow, larger at the positive pole, becomes smaller by degrees on the side toward the negative pole, where there are seen circular traces, corresponding to the forms

of arborescent bouquets. All round the positive pole you see diverging

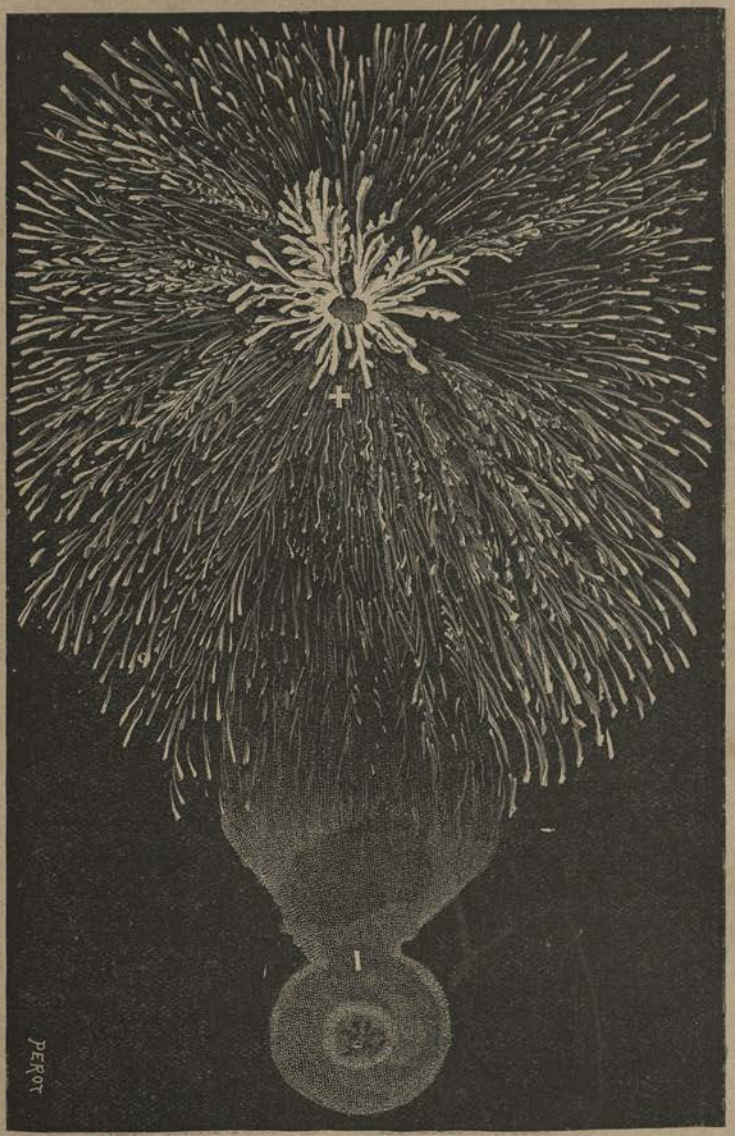

Fig. 312.—Lichtenberg figure produced by the rheostatic machine. Brush discharge.

tracks, which spread out like the branches of trees, only, as may be seen in Fig. 311, much more cut up than those at the negative pole.

This difference between the two poles we have had occasion to

FIG. 313.—Lichtenberg figure produced by the rheostatic machine. Spark discharge.

notice many times, for example, in the sparks and brushes of static electricity, as in those of induction discharges. Lichtenberg's

figures (p. 196), obtained with the electrophorus, have furnished us with characteristic examples. Planté obtained analogous figures by causing the spark of his rheostatic machine to flash along the surface of a piece of pure resin, and afterwards dusting into it a mixture of the powders of sulphur and red lead. We reproduce two of these interesting specimens of the traces of the discharge, which, having been produced by varying the distance of the points of the discharger, show very clearly how the brush differs from the spark. Figure 312 is that obtained when the distance of the points is too great to allow the spark to pass. In this case a single brush is seen; the electric movement, starting from the negative pole, and characterised by the red lead powder which adheres to the resin, does not extend quite to the positive pole. This latter pole is, on the contrary, characterised by the corona of well-marked diverging rays of flour of sulphur all round it: this corona presents at its centre no traces of the red lead powder.

It is otherwise if the distance of the points is small enough for the spark to flash: then, when the mixed powders are dusted on, the red lead is seen to spread up to the positive pole, the corona of which is open and filled in the interior with this powder (Fig. 313), showing thus that the electric movement beginning at the negative pole has spread up to the point where the positive electrification commences.

§ 8.—*Spectrum Analysis of Electric Light.*

The first observations on the dark rays in the solar spectrum as observed through a prism were made in 1802 by Wollaston. The same physicist observed the light of a candle; it seemed to him that its spectrum in the prism was divided into five images of different colours, separated by dark spaces. Finally he proved the existence of a similar division, though somewhat different in kind, in the light of an electric spark. Frauenhofer studied this latter kind of light, and found therein many brilliant rays, notably a green line, another rather feebler line in the orange, and at the red end of the spectrum another ray, still more feeble.

No one then knew what interpretation to give to the presence of these lines in the spectra of light; neither to the dark lines

seen in the sun's light, nor to the bright lines seen in electric sparks. But the subsequent discovery of the reversal of the lines by Foucault, followed soon afterwards by the explanations of Stokes and the brilliant investigations of Kirchhoff, put us in the way of a new method of analysis. We now know that we can recognise, according to the number, position, and nature of the lines observed in the spectrum, the nature of the substance the incandescence of which produces the light.

Many researches have been made to analyse by the prism the composition of the light given by the sparks of Leyden jars, by induction sparks, by the voltaic arc, and by the discharges observed in rarefied gases. We will try to give an idea of them.

In 1835, Wheatstone studied the spectra of electric light. Observing by the aid of a prism the light coming from a magneto-electric machine, he found that the spectrum of the spark drawn from mercury contained seven luminous bands, separated by dark spaces —two bands in the orange part of the spectrum, one a brilliant green, two bluish green, and one violet. By means of varying the nature of the metals used as the electrodes between which the spark passed, he saw that the lines observed varied in number and position with the substances. The influence of the medium appeared to him nil, the colours of the luminous bands in the spectrum remaining the same whether the spark passed in the air, in the barometric vacuum, in carbonic acid, or in oxygen. The influence of the metals on the nature of the lines is so marked that Wheatstone, having taken for electrodes wires made of different alloys, was able to recognise from the spectrum of the spark the brilliant lines of the two metals which composed the alloy.

The experiments of Masson confirmed those of the English philosopher, but adding an important fact to them. The lines of electric light depended truly on the nature of the electrodes, but some of them were common to different metals, varying only in their intensity from one to another. By causing the spark to pass in the air, or in different gases, at different degrees of pressure, he found that the intensity of the lines changed with the nature of the gas and with the pressure; but their number and their positions were not modified. The conclusion was the same as that which was drawn from the less numerous and less complete experiments of Wheatstone.

But the lines observed by Masson as common to the spectra of electric light obtained with different metals, have been recognised by Angström as dependent on the nature of the medium, that is to say, of the gas in which the spark passes. This mixture of lines characteristic of metals with lines characteristic of the medium surrounding, renders all researches of this kind very delicate. Moreover there are impurities in all the metals.

If the extremities of the electrodes are very near each other and the spark short, the lines of the metal predominate, without however those of the medium or of the impurities disappearing.

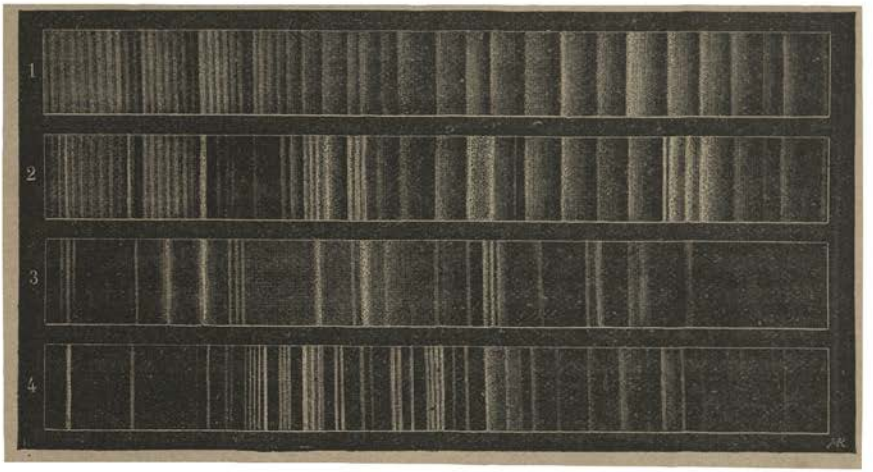

FIG. 314.—Spectra of Electric discharges: 1, Positive light of a non-condensed induction-spark; 2, Blue aureole of the negative pole of the same spark; 3, Long spark; 4, Very short spark with hydrochloric acid.

The longer the spark becomes, the weaker are the metal lines, giving relatively greater predominance to the lines of the surrounding medium (Fig. 314, 3 and 4).

The light that is obtained by the discharge of the induction coil in Geissler tubes with rarefied gas, gives a spectrum independent of the nature of the conductors. But the number and brilliancy of the lines vary considerably with the conditions of the experiment. The dimensions of the tube employed, the pressure of the gas, the intensity of the discharge are so many factors which influence the spectrum obtained.

The reader is referred to treatises on "Spectrum Analysis" for

fuller information on these matters, but we may here give (Fig. 314) a certain number of the spectra of electric light observed by Lecoq de Boisbaudran. We will follow them up with some notes to indicate the circumstances of the experiments which produced them; these notes are taken from the author named:—

Fig. 314, 1.—"This spectrum belongs to the luminous discharge, which extends from the positive pole to within a short distance of the negative pole of an induction spark of moderate length, formed in the air at ordinary pressure. The present spectrum is scarcely different from that in the capillary part of a tube filled with rarefied nitrogen; it has been successively obtained with electrodes of platinum, palladium, silver, and aluminium."

Fig. 314, 2.—"This spectrum is that of the blue negative glow of an induction spark passing in the air at ordinary pressure: it has been produced successively with electrodes of platinum, palladium, silver, and aluminium."

Fig. 314, 3.—"The present spectrum is that of the line of fire which begins when you sufficiently separate the electrodes, or when you direct a current of air on to a spark of moderate length. This spectrum is nearly identical with that which is obtained by the addition of a Leyden jar to the secondary circuit; I have reproduced it successively with electrodes of platinum, palladium, silver, and aluminium."

Fig. 314, 4.—"When a spark of middling length passes between a platinum wire and a solution of hydrochloric acid, the spectrum produced is like that which is obtained between two electrodes of platinum (spark positive pole, spark negative pole, long spark). The red line of the hydrogen acquires, however, much greater intensity."

The physicists whom we have quoted above, Wheatstone, Foucault, and Masson, have also studied the spectrum of the voltaic arc. In general the lines observed are the same as those of the spark for the same electrodes; but they are less numerous in the spectrum of the arc, which Masson attributed to lesser electromotive force required to produce the latter. Here are some details on the nature of electric spectra given by different metals when employed as electrodes:

With cadmium, the spectrum gives some very brilliant blue

and green lines. Antimony gives a great number of brilliant lines but no colour predominates, which explains the whiteness of the spark. It is the same with bismuth. The spectrum given by lead is remarkable for the extent of the violet region, where there are some beautiful lines. A green band characterizes the spectrum of zinc. Silver produces a very brilliant green, with many lines; yellow and violet are very bright in the spectrum of the spark that passes between electrodes of gold. Iron, platinum, and tin offer nothing particular. Electrodes of carbon furnish a light, the spectrum of which is distinguished by a vast admixture of brilliant rays.

We said that the lines of the metals are the same for the voltaic arc as for the spark. But there is a difference, which was recognised by Masson and confirmed by the experiments of Van der Willigen: it is that the spectrum of the arc is not modified by the influence of the surrounding medium, whilst we know that the latter adds specific lines to those of the metals which serve as electrodes for the spark. We will finish by a general remark on the spectra of electric light: they are all characterised by the great extent and intensity of the ultra-violet region; that is, they are very abundant in chemical rays.

§ 9.—*Propagation and Speed of Electric Discharges.*

Whatever may be the "mode of motion" which determines the propagation of electricity on the surface of conducting bodies or in the interior of wires forming a circuit, one cannot suppose that the propagation is instantaneous; and it is possible, as has been done for sound and for light, to try to calculate its speed. It is a problem which ever since the middle of the last century has been the subject of experiments. Deluc at Geneva, Le Monnier in France, Watson in England failed to resolve it, or at least the result of their researches was that the speed of electricity is comparable only to that of light. This is how Le Monnier proceeded. After some attempts, the result of which did not appear decisive enough, he arranged two parallel iron wires round a large enclosure; each wire was about 950 fathoms long, and their four ends were

placed at one of the corners of the enclosure, near each other: a man took an end of each of the wires in both hands; by this means forming a communication with both; thus they made only one conductor, 1,900 fathoms long, in the middle of which was placed the man, who held the two ends of the wires.

By this arrangement, the man, though placed in the middle of the whole length of the conductor to be electrified, was very near the two other ends, and could judge easily if he felt the shock at the moment when he saw the spark pass; which did in fact happen. Le Monnier having taken with one hand the end of one of the iron wires, went near the end of the other wire, with the brass wire of a Leyden jar, which he held with the other hand; and at the same instant that the spark appeared, both he and the man placed in the middle of the length of iron wire felt the shock, without the possibility of perceiving the smallest interval of time between the spark and the shock, though it would have been easy to discern even a quarter of a second, if there had been such.

Some time later, the same experimenter, in order to get a more complete proof of this phenomenon, made another experiment, in a somewhat different way, the success of which confirmed the preceding one. Having chosen a convenient place in the environs of Paris, he surrounded it with, an iron wire 4,000 fathoms, or about six miles in length. The two ends of the wire were arranged at six or seven feet distance from each other. While Le Monnier held in his hand one of the ends of the wire, another observer, who carried the Leyden jar, put the brass wire of this bottle to the other end of the iron wire. At the same instant the two observers felt the shock in their arms. The shock was less strong in this experiment than in the preceding one, because its violence was divided between the two observers; each felt only about half the shock that he would have felt if the circle of communication of each had been complete, but the result was none the less certain. The experiment was repeated, and the same effect always followed, without the least instant being discoverable between the appearance of the spark and the sensation of the shock. It appeared then that the electric discharge traverses the space of six miles in an imperceptible time.

Similar experiments were made by Watson in England in 1748,

and led to the same conclusion; and it was only a century later that we were able to determine numerically the speed of the propagation of an electric discharge. It continued to be regarded as being very great, but without being able to assign limits to it.

Biot, when describing some of the mechanical and physical effects of electric force, adds: "We must form the highest idea of the energy of this force, and of the enormous speed that electric matter possesses, seeing that, without possessing any appreciable mass when tried in the most delicate balances, it can impress on heavy and solid bodies such considerable quantities of movement. We know, in fact, that when a body sets another body into movement by its shock, the sum of the product of their masses by their speed is the same before as after the shock. What speed may we not conjecture electricity to possess in order that it may conform to this rigorous law of mechanics in the phenomena that we have described? The diameter of the whole earth would be perhaps too little to render the transmission perceptible."

The experiments of Wheatstone, in 1834, cleared up what had been necessarily obscure or conjectural in these theoretical views. The method which this physicist made use of is no other than that of the revolving mirror, of which Léon Foucault made such a happy application in the determination of the velocity of light.

The principle being the same in the two methods, we shall confine ourselves to showing briefly what arrangement the inventor adopted for the special end proposed,—the measurement of the speed of the propagation of the electric discharge.

We will suppose that a mirror M is arranged to rotate about a horizontal axis, and that there are arranged in front of it, upon a line parallel to the axis of the mirror, six metal balls, in three groups A, B, C. The two balls in the middle are each connected to the balls at the extremities by two metal wires of a certain length, 400 yards for example; the second and the fifth communicate each by a wire to the two coatings of a Leyden jar. As soon as the discharge takes place through the system, three sparks appear at A, B, and C. If the electric discharge is propagated with infinite speed, or at least quickly enough to traverse the portions P and Q, of the conducting wire in an inappreciable time, the sparks as viewed in the rotatory mirror would appear absolutely simultaneously. In the converse case, we shall

see how the mirror M enables us to recognize this want of simultaneity, and to measure the time that elapses between one spark and the other.

We must remember that the image of a luminous point in a rotating mirror is displaced, and describes an arc, having for its centre some point in the axis of rotation; and the angular value of the apparent displacement, that is of the arc in question, is exactly double the angle of rotation of the mirror. If the luminous point lasts a short time, its image will describe a limited arc, the size of which will depend besides on the speed of rotation of the mirror. As the duration of the luminous impression is about the tenth of a second, the eye will see at once all the images successively under the form of a

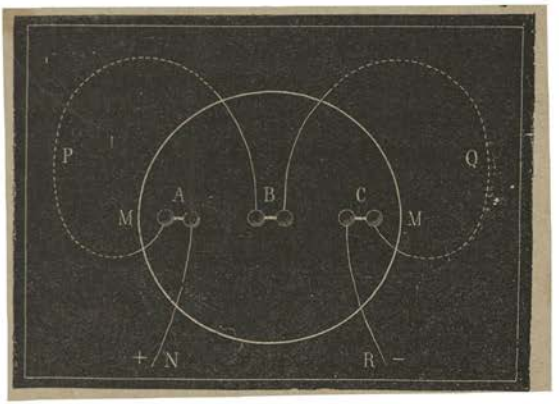

FIG. 315.—Wheatstone's experiment of the rotating mirror.

luminous track, on one condition (due to the time that the impression persists in the eye), viz., that the phenomena lasts less than a tenth of a second. That is what does happen with the electric spark, which, with the speed of a mirror turning about eight hundred turns in a second, appears under the form of a luminous band. Wheatstone measured this band and found it 24° in width. During this time the mirror had turned through half this angle, that is to say 12°, or the thirtieth part of a circumference. This first result gives an approximate value of the duration of sparks in the conditions in which this experiment was made. This duration was $\frac{1}{30 \times 800}$, or the 24000th part of a second.

Let us next see how Wheatstone was able to measure the speed of the propagation of the electric discharge. Three sparks, we said, issued at the moment of the discharge between the balls of each group. Three luminous bands were observed by reflection in the turning mirror; they were all three of the same length, thus marking the equality of the duration of each of them. But they did not begin at the same instant. If they had, the three bands would have occupied on the mirror identical positions relatively to the axis; the ends of the three parallel lines would have been at the same height, as in Fig. 316. Instead of that, the middle one seemed placed a little higher or a little lower than the end ones, according as the mirror turned in one direction or in another (Fig. 317). What may we conclude from this? That the spark issuing between the two balls in

FIG. 316.—Aspect of the three luminous bands on the hypothesis that the velocity of propagation is instantaneous.

the middle was always later in appearing than the two others, and that this delay was evidently due to the time the electric discharge had taken to traverse each of the wires, about 400 yards long, uniting the groups of balls between two gaps in the circuit.

The speed then of electric discharges is not infinitely great. To measure it, it is only necessary to evaluate the angular quantity that the middle luminous band is displaced above or below each of the others. Wheatstone found the spark from the middle to be always retarded about half a degree on the others, corresponding to a movement of rotation of the mirror to a quarter of a degree, or the 1440th part of a circumference. The mirror making eight hundred turns in a second, it is in a fraction of a second marked by the denominator, $1440 \times 800 = 1152000$, that electricity traverses each space of 400 yards, or more exactly, 367 metres. The speed of the propagation

is then 367 × 1,152,000 metres, or about 423,000 kilometres, or about 288,000 miles per second.

The exact position of symmetry of the two extreme bands, whatever may be the direction of rotation of the mirror, was considered by Wheatstone to prove also two things: first, that electricity is not propagated in one direction only but in two directions at once; second, that the speed of its propagation is independent of the direction of the current.

The experiments of Wheatstone were made in 1834. But since that time electric telegraphy having been very much developed, it is possible to measure the speed of electric discharges by using the long insulated metal wires which unite the stations between which signals and despatches are exchanged. We sum up in the following table different numbers obtained by different experimenters. These num-

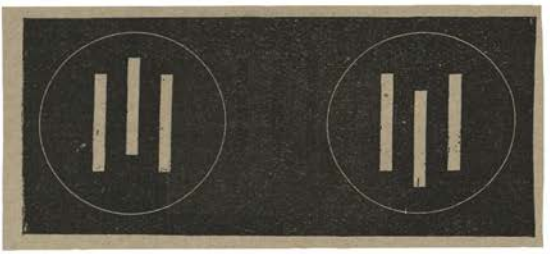

FIG. 317.—Images of the sparks in the rotating mirror.

bers present considerable variety, which are owing to many causes. There is firstly the difference of methods and the errors of the observations which are so to speak inherent in them, but which are far from rendering an account of the divergences. In truth, the speed of the propagation of electric discharges is not, as the speed of light, susceptible of a single definition; or rather it varies with the conditions of the experiment, the nature of the conducting circuit, and the electromotive force of the source. Faraday, after Wheatstone's experiments, suspected that a different result could be attained if you put the ends of the wires into immediate communication with large insulated metallic surfaces, acting as condensers. This prediction has been verified in subterranean telegraph wires, as well as in sub-marine cables, the insulating coating of which, consisting of gutta-percha plunged in sea water, forms with the wire a condenser.

The result of this is a considerable increase of the electric capacity of the wires, and a consequent delay in the speed of the propagation of the discharge.

SPEED OF THE PROPAGATION OF ELECTRIC DISCHARGES.

Observers.	Kilometres traversed in a second.	Nature of Conductor.	Observations.
Wheatstone	423,000	Copper wire	Discharge of a Leyden jar.
Fizeau and Gounelle. .	100,000	Iron ,,	Telegraph from Paris to Amiens and Rouen.
Fizeau and Gounelle. .	180,000	Iron ,,	Telegraph from Paris to Amiens and Rouen.
O'Mitchell	45,600	Iron ,,	Telegraph from Cincinnati to Pittsburg.
Walker	30,000	Iron ,,	Telegraph from Philadelphia to Cambridge.
Observatories of Greenwich and Edinburgh .	12,200	Copper ,,	Overhead telegraph.
Observatories of Greenwich and Brussels . .	4,300	Copper ,,	Submarine cable
Faraday	1,200	Copper ,,	Subterranean wire.
Felici	260,000	Copper ,,	Discharge of a Leyden jar.
Gould	25,600	Iron ,,	Telegraph from Saint Louis to Washington.

[It should be carefully noticed that what Wheatstone was measuring in the above experiments was not the speed at which electricity itself travels. What he really measured was the time taken to charge a line with a ball on the end of it up to such a potential that it could throw a spark across the air to the ball in its immediate neighbourhood; and it is obvious that this time depends upon the capacity of the line and ball. The experiment tells us nothing whatever about the rate at which electricity itself flows: it gives us rather a measure of the rate at which an electric wave is propagated. A sound (that is to say, an air wave) may travel through air at about 1,100 feet per second, but at the same time the air may be moving along at quite a different speed. Some of the other experimenters used quite a different apparatus, such as galvanometers and Morse telegraph instruments, none of which work instantaneously in themselves. Further, respecting Wheatstone's conclusion that electricity is propagated in two directions at once, it may be observed that in his experiments one end of the wire was connected to the outside

coating of the Leyden jar, and the other was connected to the inside. Hence when the "discharge" occurred, electricity began to flow into one end of the wire and to run out of the other end at the same instant, and it was not until a short time later that the flow had reached the middle. Consider a level canal full of water. Then let some water be suddenly let in at one end, and also at the same instant let water be suddenly let out at the other. Two disturbances, one tending to raise the level, the other tending to lower the level, will start from opposite ends, but it will be some time before the water at the middle of the canal will begin perceptibly to flow. The greater the capacity of the canal the longer will the time be before a perceptible flow is produced at the middle of the canal.—ED.]

CHAPTER XII.

ELECTRIC METEOROLOGY.

§ 1.—*Identity of Lightning and Electric Phenomena.*

THE phenomena of electricity that we have had occasion to describe up to the present have been experimental almost without exception. Thanks to the processes designed by the experimental philosopher, their effects so varied and powerful have been made manifest to our senses. Observation pure and simple has done almost nothing for their discovery, and the science of Electricity, like that of Magnetism (which now is one with it), is, so far as concerns the phenomena in question, an experimental science, or to be more precise, a science of observation based exclusively on direct experiment. Very few of the facts on which it is based offer themselves spontaneously to the study of the philosopher; and this doubtless explains why Magnetism and Electricity have been the last branches of physics to be firmly established, why long ages passed before the true subject matter of these sciences presented itself to the inquiring investigator. Two facts only, the attraction of the magnet for iron and that of rubbed amber for light bodies, were the modest points of departure for these two sciences, which the researches of Oersted, of Ampère, and of Faraday finally moulded into one.

It would be, we must admit, a singular exception in the history of the physical and natural sciences if what we have just said were true in an absolute sense. We know that it is not so. In truth, since the beginning of time, nature has pointed out to man in a striking manner, in phenomena on a grand scale, the materials for a new science. Polar auroras, though relatively rare in the temperate climates, where growing civilization permitted man to speculate philosophically on

the phenomena he witnessed, have been known and observed from the earliest ages. The thunderstorm, the lightning flash, the thunder peal, and other similar phenomena could not fail to become objects of scientific researches. But the thunderstorm, like the aurora, remained an enigma down to the not very remote date when electric attractions and repulsions displayed themselves, accompanied by certain

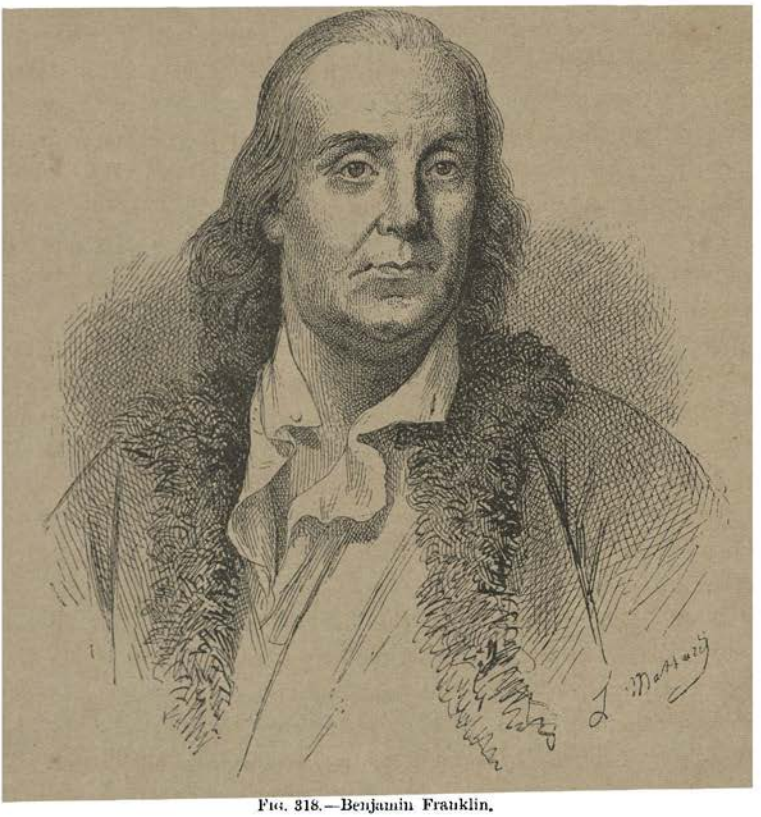

FIG. 318.—Benjamin Franklin.

luminous effects, in the first modest experiments of Otto von Guericke, Wall, and Gray, and when Benjamin Franklin showed, by a happy and bold experiment, the identity of the lightning-flash with electricity.

The memoir in which the illustrious American philosopher compares the effects of lightning with those of electricity, dates from November, 1749; this was two years and a half before his experi-

ments on storm clouds, and those of the French philosopher, Dalibard, both of which were carried out in May, 1752. At that epoch he had just recognised the power of points; two ingenious experiments in which this power was put into play, furnished him with a new analogy, and suggested to him to verify by the storm clouds the truth of his conjectures. Having suspended by silk threads to the ceiling of his room a tube of gilt paper, 10 feet in length and a foot in diameter, Franklin charged it with electricity. Then presenting to the tube, at the distance of a foot, the point of a needle, the tube was instantly discharged; if, on the contrary, he presented to it a blunt body, an iron bolt or punch rounded at the end, he found it was necessary to put it within three inches bofore it could cause the discharge, which then, he said, took place with a sudden crackling. Suspending in the same way some great brass scales, the pans of which were supported by silk cords, a foot from the floor, he electrified one of the pans. The twisting of the suspending cord caused the scales to turn; he placed the iron punch underneath, below a point of the circumference described. When the pan which was electrified passed over it, it lowered itself, came in contact with it, and thus discharged itself. But if the end of the punch was furnished with a needle, the point uppermost, the pan passed above it without approaching, and the discharge took place silently; or if in its course the pan had come near enough for a spark to strike, it could not, because it would have been discharged beforehand.

"Now (says Franklin) if the fire of electricity and that of lightning be the same, as I have endeavoured to show at large in a former paper, this pasteboard tube and these scales may represent electrified clouds. If a tube only ten feet long will strike and discharge its fire on the punch at two or three inches distance, an electrified cloud of perhaps 10,000 acres may strike and discharge on the earth at a proportionably greater distance. The horizontal motion of the scales over the floor, may represent the motion of the clouds over the earth; and the erect iron punch, a hill or high building; and then we see how electrified clouds passing over hills or high buildings at too great a height to strike, may be attracted lower till within their striking distance. And lastly, if a needle fixed on the punch with its point upright, or even on the floor below the punch, will draw the fire from the scale silently at a much greater than

the striking distance, and so prevent its descending towards the punch; or if in its course it would have come nigh enough to strike, yet being first deprived of its fire it cannot, and the punch is thereby secured from the stroke." (Franklin, *Experiments and Observations on Electricity*, p. 64.)

This minute analysis of the effects resulting from the power of points, and this comparison of experiments made on a small scale with phenomena observed in storms, did not remain fruitless in Franklin's thoughts; he did not fail to draw a practical consequence from it at once—the invention of lightning conductors; at the same time he conceived a method of observation for showing the truth of his theories.

"I say, if these things are so, may not the knowledge of this power of points be of use to mankind, in preserving houses, churches, ships, &c., from the stroke of lightning, by directing us to fix on the highest parts of those edifices, upright rods of iron made sharp as a needle, and gilt to prevent rusting, and from the foot of those rods a wire down the outside of the building into the ground, or down round one of the shrouds of the ship, and down her side till it reaches the water? Would not these pointed rods probably draw the electrical fire silently out of a cloud before it came nigh enough to strike, and thereby secure us from that most sudden and terrible mischief?

"To determine the question, whether the clouds that contain lightning are electrified or not, I would propose an experiment to be tried where it may be done conveniently. On the top of some high tower or steeple, place a kind of centry-box big enough to contain a man and an electrical stand. From the middle of the stand let an iron rod rise and pass bending out of the door and then upright 20 or 30 feet, pointed very sharp at the end. If the electrical stand be kept clean and dry, a man standing on it when such clouds are passing low, might be electrified and afford sparks, the rod drawing fire to him from a cloud. If any danger to the man should be apprehended (though I think there would be none) let him stand on the floor of his box, and now and then bring near to the rod the loop of wire that has one end fastened to the leads, he holding it by a wax handle; so the sparks, if the rod is electrified, will strike from the rod to the wire, and not affect him." (*Experiments and Observations*, p. 65.)

Franklin was indeed the first instigator of the experiments which showed the identity of lightning and electricity, but he was not the first to realize them. It was a French philosopher, Dalibard, who had this honour. Knowing of Franklin's suggestion, he put up, in a garden at Marly, several insulated iron rods terminated with points. A storm cloud passed over; from one of them, which was 14 metres high, he was able to draw sparks a foot in length, and to charge Leyden jars. A thunder clap was heard at the same instant. This decisive experiment took place on May 10, 1752. A month after, in America, Franklin made with his son the famous experiment of the kite, which was repeated the following year by De Romas. Priestley, in his *History of Electricity*, gives the following graphic account of the experiments of De Romas:—

"This gentleman was the first who made use of a wire interwoven in the hempen cord of an electrical kite, which he made 7 feet and a half high, and 3 feet wide, so as to have 18 square feet of surface. This cord was found to conduct the electricity of the clouds more powerfully than a hempen cord would do, even though it was wetted; and being terminated by a cord of dry silk, it enabled the observer (by a proper management of his apparatus) to make whatever experiments he thought proper without danger to himself.

"Thinking himself now secure enough, and not being incommoded by anybody very near him, he took notice of what passed among the clouds which were immediately over the kite, but could perceive no lightning either there, or anywhere else, nor scarce the least noise of thunder, and there was no rain at all. The wind was west, and pretty strong, which raised the kite 100 feet higher, at least, than in the other experiments.

"Afterwards casting his eyes on the tin tube which was fastened to the string of the kite and about 3 feet from the ground, he saw 3 straws, one of which was about 1 foot long, a second 4 or 5 inches, and the third 3 or 4 inches, all standing erect, and performing a circular dance, like puppets, under the tin tube, without touching one another.

"This little spectacle, which much delighted several of the company, lasted about a quarter of an hour; after which, some drops of rain falling, he again perceived the sensation of the cobweb on his face, and at the same time heard a continual rustling noise like that

of a small forge bellows. This was a further warning of the increase of electricity; and from the first instant that Mr. De Romas perceived the dancing straws, he thought it not advisable to take any more sparks even with all his precautions; and he again entreated the company to spread themselves to a still greater distance.

"Immediately after this came on the last act of the entertainment, which Mr. De Romas acknowledged made him tremble. The longest straw was attracted by the tin tube, upon which followed three explosions, the noise of which greatly resembled that of thunder. Some of the company compared it to the explosion of rockets, and others to the violent crashing of large earthen jars against a pavement. It is certain that it was heard into the heart of the city, notwithstanding the various noises there.

"The fire that was seen at the instant of the explosion had the shape of a spindle eight inches long and five lines in diameter. But the most astonishing and diverting circumstance was produced by the straw which had occasioned the explosion following the string of the kite. Some of the company saw it at forty-five or fifty fathoms distance, attracted and repelled alternately, with this remarkable circumstance, that every time it was attracted by the string, flashes of fire were seen, and cracks were heard, though not so loud as at the time of the former explosion.

"It is remarkable that, from the time of the explosion to the end of the experiments, no lightning at all was seen, nor scarce any thunder heard. A smell of sulphur was perceived, much like that of the luminous electric effluvia issuing out of the end of an electrified bar of metal. Round the string appeared a luminous cylinder of light three or four inches in diameter, and this being in the daytime, Mr. De Romas did not question but that, if it had been in the night, that electric atmosphere would have appeared to be four or five feet in diameter. Lastly, after the experiments were over, a hole was discovered in the ground, perpendicularly under the tin tube, an inch deep, and half an inch wide, which was probably made by the large flashes that accompanied the explosions.

"An end was put to these remarkable experiments by the falling of the kite, the wind being shifted into the east, and rain, mixed with hail, coming on in great plenty. Whilst the kite was falling, the string came foul of a penthouse; and it was no sooner disengaged

than the person who held it felt such a stroke in his hands, and such a commotion through his whole body, as obliged him instantly to let it go; and the string, falling on the feet of some other persons, gave them a shock also, though much more tolerable.

"The quantity of electric matter brought by this kite from the clouds at another time is really astonishing. On August 26, 1756, the streams of fire issuing from it were observed to be an inch thick and 10 feet long. This amazing flash of lightning, the effect of which on buildings or animal bodies would perhaps have been equally destructive with any that are mentioned in history, was safely conducted by the cord of the kite to a non-electric body placed near it, and the report was equal to that of a pistol.

"Mr. Romas had the curiosity to place a pigeon in a cage of glass, in a little edifice, which he had purposely placed so that it should be demolished by the lightning brought down by his kite. The edifice was accordingly shattered to pieces, but the cage and the pigeon were not struck."

Experiments similar to these were made by a great many learned men in France, in England, Italy, and Russia, not without danger, as was proved by the death of Richmann at St. Petersburg. This experimenter had arranged, on the roof of his laboratory, a vertical rod of iron, insulated, which communicated by a chain, also insulated, with a metal rod fixed to the ceiling, and terminated in a ball. Having gone too near this during a storm, Richmann was struck on the head by a spark, and fell dead.

The obvious result of these multiplied experiments is to demonstrate the truth of the conjectures of Gray and of Wall and the precise statements of Franklin, that the clouds are charged with considerable quantities of electricity, and that lightning and thunder are, on an immensely larger scale, the same phenomena as accompany the electric discharges produced on the small scale in the laboratory. A rapid survey of the principal effects of lightning and of the phenomena of thunder-storms will complete the study of this important matter.

§ 2.—*Lightning and Thunder.—Different Forms, Colours, Duration, and Length of Lightning Flashes.*

Lightning is the spark which issues either between two clouds, or between a cloud and the earth. After an interval of time, which depends on the distance of the observer from the region of the atmosphere where the discharge takes place, the noise of thunder is heard sometimes bursting like a loud detonation, sometimes making itself heard in more or less heavy prolonged rumblings. Thunder-clouds are formed of masses of condensed spherules of moisture falling slowly through the air, and most frequently piled up in immense masses.

Arago, however, cites many examples of isolated storm clouds of *small* dimensions, whence lightning and thunder have issued.

The thunder-clouds, besides having a general movement of translation in the direction of the prevailing wind, are often animated by internal movements, uniting or dividing, and tearing asunder, as if there were between these different parts attractions and repulsions. The explanation of these last phenomena is easy, if you admit that the cloudy masses are changed, some with positive, and others with negative electrification. When two superposed clouds are charged with contrary electrification, they attract each other, approach, and as soon as the distance is sufficiently small, a discharge takes place, and a flash of lightning darts between them. Most commonly this discharge is only partial, resulting from the imperfect conductivity of the vapourous masses forming the cloud; and a series of smaller flashes of lightning, each followed by a small detonation, succeeds the first spark. It is probable besides that the same causes which have developed the electricity in the storm-cloud continue after the first discharge, and give place to a fresh electrification, which after a time is again discharged.

The forms of flashes of lightning exhibit great variety; the most frequent form is that of a sinuous track; sometimes it presents a series of rectilinear tracks in a zigzag, like the sparks of our electric machines.

But it is possible that the real form may be spiral, and that the apparent angles proceed from the contours of the luminous spiral being seen in oblique perspective.

More rarely the same flash divides into two branches, sometimes into three or four. These *bifurcated*, *trifurcated*, and *ramified* flashes have their point of departure in the cloud; the track, at first a single one, divides into two or more branches on arriving near the earth. Arago cites many examples of it. Kæmtz says that during violent storms, the principal flash emits lateral branches, or appears ramified at one end. We have ourselves seen, and sketched in one storm several bifurcated flashes, and one with four distinctly separate branches. Multiple flashes rarely appear in Europe. Arago only quotes one example of bifurcated lightning beyond those observed by the Abbé Ferrara in 1763, in the smoke of Etna. It is not, however, so everywhere. Liais, in his *Espace céleste*, recounts a storm that he observed at Rio Janeiro, January 30, 1859:—"At seven o'clock some flashes appeared in the east, and at ten minutes past seven the storm had attained its full intensity. At this moment there appeared continuously, at intervals of one or two seconds, zigzag flashes of lightning, more than the third of which were bifurcated. Besides these bifurcated flashes, and those with three or four branches, which were also very frequent, not a minute passed without the appearance of what may be called arborescent flashes. These were tracks of fire which divided into many principal branches, which in their turn divided into a multitude of boughs. One of them, which I particularly remarked, and which appeared to propagate itself as it descended, divided at first into three parts, which subdivided afterwards, so as to form in all fifteen branches.

"I remarked also flashes with many more branches, so many that the whole details could not be fixed on the mind. The most remarkable of these latter ones was radiant, not arborescent, that is to say, it propagated in every direction at once, starting from a centre, whence issued six branches, which subdivided into a multitude of secondary tracks."

Liais adds that he has frequently since seen the same phenomena of divided flashes, which have also been seen by Poey at Havana, and appear to be frequent in all the stormy countries of the intertropical zone.

The colour of lightning is usually a dazzling white; it also frequently affects a violet tint, or purple, or more rarely green. Violet is the colour of the spark in rarefied gas; Kæmtz remarked that this colour was particularly observed when the flashes were very high, and were therefore formed in regions where the air is very rare.

Arago, in his notice *on Thunder*, classifies lightning flashes under three classes: the first comprehends those we have just described, and which are known in Italy by the name *sactte*. "According," he says, "to an opinion commonly received amongst us, both amongst physicists and the general public, it is principally, if not exclusively,

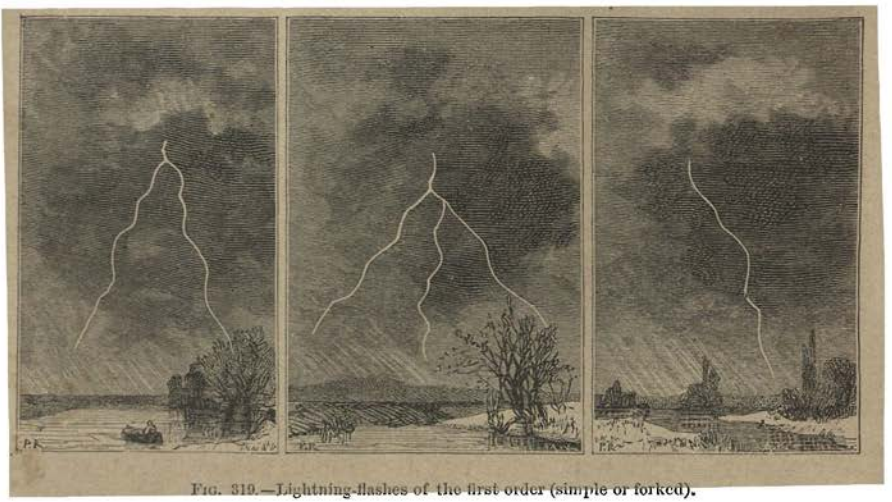

FIG. 319.—Lightning-flashes of the first order (simple or forked).

the *sactte*, the *serrated* flashes, the *forked* flashes, the *zigzags*, which carry with them fire and destruction; such flashes constitute *lightning* properly so called."

In the second class are arranged flashes, the light of which, "instead of being concentrated into sinuous lines of no apparent width, extend over immense surfaces. They have neither the whiteness nor the brilliancy of fulminating flashes. Often the tint is an intense red, but sometimes blue and violet prevail." It is probable that many flashes of this second class are only such in appearance, and belong really to the first class, the luminous track issuing behind thick cloudy masses, which hide it from the observer.

In this case it is the edges only of these clouds that appear illuminated. The true lightning of the second class are doubtless due to partial discharges occurring in the interior parts of the same cloud; they have been compared to the lights produced on a plate of damp glass, when it is used to discharge an electric machine.

The third class of lightning flashes includes *ball flashes*, which are more often known as *globular lightning*. This particular form of discharge is much more rare than the two others; it is distinguished also

FIG. 320.—Diffused lightning of the second order.

by the slowness of its movement and by its duration, which far exceeds that of ordinary lightning. The following fact, which we give in Peltier's words, will afford an idea of the singularity of the phenomenon of globular lightning:—

"On August 28, 1839," he says, "in the midst of a violent storm, the black and low clouds of which almost touched the tops of the buildings, the stroke fell in the middle of the court of the unfinished central office of the custom-house in the city of Paris,

in course of building. This thunderbolt was in the form of a great globe of fire, and was accompanied by a train of vapour; it struck the soil, formed of fresh rubbish, and dug a hollow eighteen centimetres in diameter; here it moved furiously about, turning round, and threw up the loose earth; then it rebounded, to fall again at three metres' distance, where it made another excavation nine centimetres in diameter, being continually in violent agitation. Very soon the globe of fire rebounded again from this cavity on to the wall of the enclosure, along which it followed the coping for about thirty metres. Arrived at the corner of the wall opposite the Hospital of Saint Louis this globe, already very much diminished in volume, dashed along the street, over the pavement wet with the rain; here it dragged itself along a long serpentine furrow, passed the entrance gate of the hospital, and disappeared in the middle of the court opposite the church. As the time went on and its contact was prolonged, you could very clearly see its mass diminish; when it arrived in the middle of the court of the Hospital of Saint Louis, it was nothing but a thin strip, with but little light, which disappeared suddenly. At the moment of the fall of this globe in the court of the custom-house, all the workmen and clerks who were at shelter under the sheds felt a smart electric shock; and they were all impressed by the strong sulphurous smell which it left behind."

Out of twenty cases of globular lightning quoted by Arago, five presented this peculiarity, that the globe burst with violent detonations at the end of its course. The lightning which struck Professor Richmann, in 1752, was in the form of a globe of fire.

This third form of lightning observed during storms remained a long time unexplained. The sinuous sparks, and those that were zigzag or bifurcated, had their respective analogues in the electric discharges of our machines. Nothing was known like the explosive globes,[1] of which we have just had a description, until Planté obtained with his secondary batteries the remarkable luminous effects mentioned in a preceding chapter. In referring back to the globular flames represented in Figs. 305 and 306, it is difficult not to be struck by the analogy they offer with lightning of this third class. The opinion of the author of these experiments is, that the nature of the

[1] [A curious case of a globular discharge occurring accidentally with a Leyden jar is, however, recorded by Cavallo in his book.—ED.]

fulminating globes observed during great storms is in all probability the same as that of globular sparks produced by the aid of electric currents of a very high electromotive force. Thus the globe would be formed of incandescent rarefied air and gas resulting from the decomposition of the vapour of water, as well as to the state of rarefaction and incandescence. It is probable that to these may be added the cosmic particles which the current meets in the atmosphere. Though these particles exist in the air in very small quantities, it is known that those which have a mineral origin, like iron, chalk, and silica, are substances endowed with great irradiating power; their incandescence doubtless contributes in a great degree to the luminous brilliancy of ball lightning.

Sometimes it happens that the globes of fire are multiple; either the primitive globe divides or there are several successive ball discharges. In this case the phenomenon would belong to a special form of flashes, which Planté calls "bead flashes." In a storm which burst over Paris on August 18, 1876, Planté made the following observation :—

"Towards seven in the morning," he says, "at the moment when the storm began to descend on Paris, one flash remarkable amongst the others discharged itself from the cloud to the ground, describing a curve like an elongated S, and remained visible during an appreciable time, forming a string of brilliant beads scattered along a very thin luminous thread (Fig. 321)." According to the newspaper accounts there were several successive discharges of globular lightning. "This kind of lightning," adds Planté, "appears to constitute a phenomenon indicating a transition between the ordinary form of lightning in straight or sinuous tracks and the globular form. One can imagine that the grains or beads of lightning may acquire a certain size and produce globes of fire. We have concluded from this observation that fulminating globes, which fall in greater or lesser numbers, accompanied by the sound of thunder, and which disappear immediately, may be considered as derived from a 'bead flash.' This formation of luminous beads alternating with tracks of fire, must be the consequence of the pouring of the electric discharge through a ponderable medium, and may be compared to a string of incandescent globules which a long metal wire would produce melted by a voltaic current, and the ends of which would remain an instant suspended in

fusion at the poles of the battery; or also to the nodosities observable in a vein of running liquid. Such agglomerations of electrified and luminous matter would naturally be slower in dissipating than the track itself which unites them, thus explaining the apparent persistence of the flash."

Various observers, Renou, Von Tricht, Daguin, and Joule, have since confirmed the existence of cases of flashes divided into distinct luminous lines, so that it seems legitimate to form a fourth

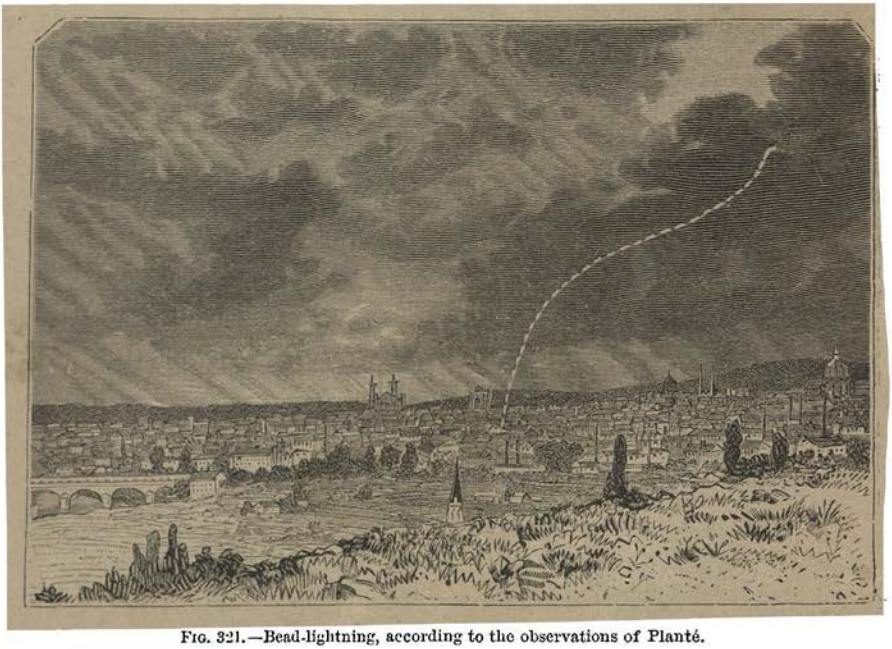

FIG. 321.—Bead-lightning, according to the observations of Planté.

class of flashes intermediate between the first and third, that of *bead lightning*.

Sometimes in warm summer evenings one sees the horizon furrowed with gleams of *summer lightning*, unaccompanied by thunder, and often called *heat lightning*. The absence of clouds for a long time caused it to be supposed that this was a special phenomenon. In reality this effect is mostly due to ordinary storms too distant for the rolling of the thunder to pierce through the space which separates them from the observer, whilst the flashes of light reflected by the upper layers of the atmosphere are easily seen at this distance.

Let us suppose two points distant from each other 111 kilometres, or about 70 miles. One of the horizons surpasses the other by 971 metres, or more than 600 miles. It follows that lightning taking place at the vertical height of a kilometre is visible at the other station. *A fortiori* would a flash be seen that originated at the height of 2 or 3 kilometres, or reflected by clouds of this height. Refraction adds again to this possibility. Now it is known that the noise of thunder ceases to be perceptible at a much less distance. Some good meteorologists are however convinced that summer light-

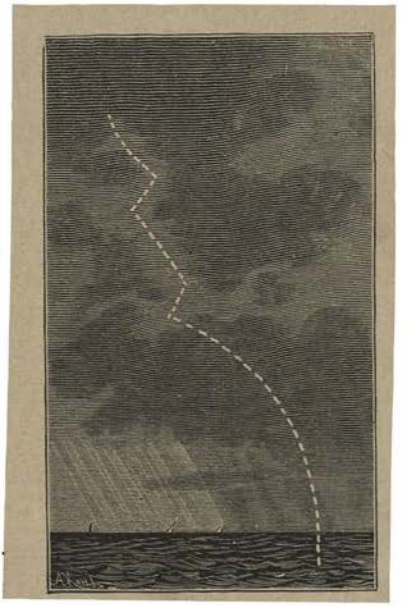

FIG. 322.—Bead-lightning, observed by Joule, July 17, 1877.

ning is a special phenomenon, and is not the reflection in the air of a distant thunderstorm.

When the luminous track of lightning of the first class meets the eye, it generally appears to have a sensible duration. The image is only effaced after an interval, which may be roughly estimated as a fraction of a second ; but it is only an impression due to the persistence of the luminous sensation on the retina of the eye. Wheatstone measured, at night, by the aid of a very ingenious method, the average duration of flashes. He made use of a wheel having a great

many spokes of dull silver, which he turned with great rapidity on its axis. If the wheel is suddenly illuminated during its rotation by any light the duration of which is appreciable, for example, $\frac{1}{10}$th of a second, each spoke, since it is displaced during this time, will appear visibly enlarged, in consequence of the persistence of the luminous impressions on the retina. The whole area of the wheel would appear more or less continuous, just as a carriage wheel which passes rapidly before us appears to have a confused multitude of spokes. Now Wheatstone found it was useless to increase the rapidity of rotation: always, whenever a flash illuminated the wheel, it appeared stationary, and all the spokes remained distinct to sight, and still. He concluded from numerous experiments that lightning does not last the thousandth part of a second.

The violence of the discharge effected between two storm clouds gives place to a noise that we know under the name of *thunder*. It may be noted that the explosion is the more sudden and the more brilliant the less the distance from the observer at which the flash takes place; but in almost all cases the detonation is accompanied by a prolonged rolling sound. The cause of the persistence of the noise of the discharge is probably due to two causes. Firstly, it has been proved that flashes are often many miles in length. One of the two ends of the flash may be nearer than the other to the listener, and though the sound is produced at the same instant through the whole length of the flash, as it takes a second to traverse 1,115 feet, it takes about thirty seconds for a difference of six miles' distance. Besides, the sound re-echoes on the clouds and on the ground, giving place to more or less prolonged peals. The zigzag form of the lightning is accountable for the rattling or rolling sound that is often heard, and which, while it lasts, often seems to burst out with redoubled power.

Everybody knows that between the instant of seeing the flash and the hearing the thunder there elapses more or less time; and it is well known that this interval is due to the difference which exists—and a considerable difference it is—between the speed of light and the speed of sound. By noticing exactly the length of this interval, one may deduce, by a very simple calculation, the distance which separates the observer from the nearest point of the flash. Reckoning the speed of sound at the temperature of 15° (of the Centigrade scale) to be 340 metres, or 1,115 feet per second, all that one has to do is to

multiply this number by the number of seconds that have elapsed. Arago reports an observation made by De Lisle in 1712, according to which there was an interval of 72 seconds between the flash and the noise of the thunder: this gives for the distance of the cloud from the observer more than 24 kilometres, or nearly 15 miles. If the rolling of the thunder be considered as due exclusively to the duration of the propagation of sound along the whole length of the line travelled by the flash, then, by noting the time the rolling lasts, you may calculate a minimum value of the length in question. In fact, the time between the beginning and end of the sound is nothing but the difference between the time the sound takes to come in straight lines from the extremities A and B of the flash (Fig. 323) to

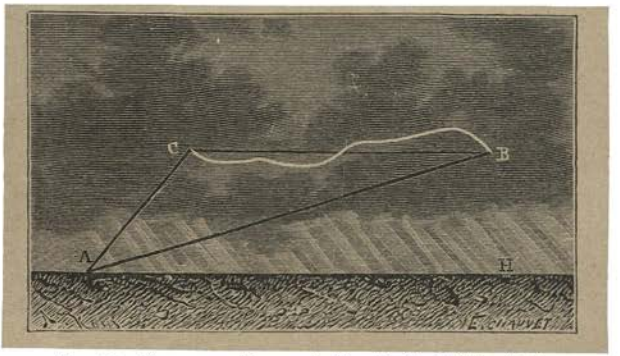

FIG. 323.—Measurement by sound of length of a lightning flash.

the ear of the observer. On multiplying this by 340 metres, or 1,115 feet, you will have the difference in length of the two lines BC, AC. Now the straight line CB cannot be less than, and may be greater than this difference; much greater, in fact, if the flash is one with zigzags and sinuosities. Thunder-claps have been heard the rolling of which lasted 45 seconds. The calculation in this case, on the hypothesis we have given, makes 15 kilometres, or over 9 miles, for the maximum length of the flash.

The noise of thunder will obviously be the more intense as the distance from us to the flash is less. But it is likely that there is a characteristic difference between certain thunder claps and others. When the lightning flashes forth, that is to say when the electric discharge occurs, not from one cloud to another, but from the cloud

to the earth, the detonation is quick, jerking; there are crashings like immense tearings, evident indications of the violence with which the mutually opposed charges of electricity on the clouds and on the earth beneath have burst through the intervening non-conducting air. But in any case what is the physical cause of the noise of thunder?

The ancients, who knew nothing of electricity, could not conceive of thunder as anything but the result of a purely mechanical shock. Seneca, speaking of the fact that two hands struck together produced a loud noise, concluded from that that the collision of two enormous clouds ought to sound with a very great crash; again, he compares thunder, "the sound of which is sharp, even penetrating, to the noise made by the bursting of a bladder on a person's head." Lucretius also explains thunder by the shaking of the clouds, or their tearing asunder. "Another reason," he says, "why thunder often appears to shake the world with its terrific agitations, so that one would think we were on the point of ruin and the destruction of the vast machine of nature, is that suddenly a hurricane, formed by a rush of rapid winds, becoming ingulfed in the clouds, and inclosed there, incessantly amasses in its whirlings cloud upon cloud, so that there remains a hollow in the mass. Then, when its violence and its impetuous energy has shaken everything, with what a frightful crash it bursts and goes away: and this is not marvellous, since a little bladder full of wind, if a hole is suddenly made in it, produces a similar noise."

Descartes' explanation of the noise of thunder is analogous to that of the noise of avalanches: the highest clouds are falling down on to the lowest. This was the same as the opinion of Seneca.

There is no doubt but that the phenomenon is of the same nature as the crackling of the smallest electric sparks, only on a different scale. The quick mutual neutralisation of the plus and minus charges present sets up in the air along the whole length of the luminous furrow a sudden displacement of the air-particles which, propagating itself in the surrounding medium, produces sound, the intensity of which is according to the energy of the motion thus imparted to the mass.

This sudden displacement of the air-particles can be explained in several ways. Some people think that electricity opens a passage

through matter, thus making a vacuum behind it, somewhat as does a projectile thrown with great force. Sound would be produced, on this hypothesis, by the quick inrush of air, as happens in the experiment of the bursting bladder. Pouillet considered this explanation as insufficient, and remarked that the passage of a cannon ball through the air only produces a hissing, and nothing which resembles the noise of thunder. The following is the explanation which this philosopher gives:—"When a spark issues between two bodies there is decomposition and recomposition of electrification between all the layers where it appears, and consequently vibration more or less violent in their ponderable matter; it is a sort of tearing or quick separation, as is seen in the experiment of piercing a card; it is a vibration which makes the noise propagating itself afterwards in all the surrounding mass."

Planté admits that it is the vacuum produced in the mass of ponderable matter traversed and rarefied by the discharge which causes the noise of thunder. "But how," he asks, "does electricity produce the vacuum? This has been asked for a long time past. Our experiments admit, we think, of a simple answer: by the powerful and instantaneous calorific action which electricity possesses, and which even vaporises all matter placed in its passage."

[It may be remarked in passing that Sir William Thomson has shown that the discharge of an air condenser is accompanied by a distinct sound, which is attributable to the sudden release of the electric stress on the intervening layer of air. It is quite conceivable that part of the noise accompanying a lightning flash is due to the sudden change in the electric stress in the air in immediate proximity to the flash.—ED.]

§ 3.—*Physical, Chemical, and Physiological effects of Lightning.*

The effects of atmospheric electricity, when it is manifested in lightning and thunder, are so wonderfully various, often so very strange, and apparently so difficult to explain, that a whole volume would be necessary to describe and comment upon them. The only thing we propose to do here is to show by some selected examples that the effects are identical, except in magnitude, with those of the

discharges of electric machines, in confirmation of the truth that lightning and electricity are phenomena of the same nature.

We will deal first with the *mechanical effects*. We meet here with extremes; some phenomena are of incredible violence, others of inconceivable delicacy. Here are some facts that we take from a memoir of Arago's *Sur le Tonnerre*.

"In the night of April 14th, 1718, a flash of lightning overthrew the roof and walls of the church of Couesnon, near Brest, as if done by the explosion of a mine. Stones were thrown *in all directions* to the distance of sixty yards. On August 6th, 1809, at Swinton, three miles from Manchester, lightning produced remarkable mechanical effects on part of a house belonging to Mr. Childwick. At two o'clock in the afternoon, after repeated discharges of distant lightning, which seemed to be approaching, a frightful explosion took place. It was immediately followed by torrents of rain. For some minutes a sulphurous vapour surrounded the house. The outside wall of the small building, cellar, and cistern *was torn up by its foundation and lifted up bodily;* the explosion carried it vertically, without overturning it, to a short distance from the place which it had occupied. One of its ends had been moved nine feet, the other four. The wall thus lifted and carried was composed of 7,000 bricks, and, without counting the mortar, would weigh about twenty-six tons."

Here is another fact of transport quoted by Daguin:—"In 1852, at Cherbourg, lightning broke the low mast of an unarmed ship; a piece, two metres in length and twenty centimetres square at the thickest end, was thrown with such force that it struck, at a distance of ninety-eight yards, against an oaken partition three centimetres thick, into which the large end was thrust, making a hole there like that which a cannon ball would have made."

We might recite by thousands the destructive effects of lightning. On the other hand it sometimes leaves almost imperceptible traces of its passage; piercing, for example, innumerable holes a few millimetres in diameter in the panes of a window without breaking them.

Among the physical effects of lightning the fusion of metals is, if not one of the most frequent, at least one of the most certain and most characteristic. Seneca, Pliny, and Lucretius may have been carried away by their imagination when they related that "lightning

melted the sword in the scabbard, the silver in the purse, and made the iron of the javelin flow along the wooden handle without either the scabbard, the purse, or the handle taking fire, that it dissolved brass and made gold boil," but it has at least been completely confirmed by accurate observers that lightning is capable of melting and volatilising metallic wires, and of soldering together the rings of an iron chain. In 1827 the packet-boat *New York* having been struck by lightning, the point of its lightning-conductor, forming a cone one foot long and a quarter of an inch in diameter at the base, was melted; so also was the chain which connected the pointed tip with the sea, and which was formed of iron links a quarter of an inch in diameter and eighteen inches in length, united by intermediate rings. This chain went obliquely from the end of the great main-top-gallant mast to the sea. Its length was certainly not less than forty-three yards. After the flash of lightning all that remained of it, all that could be found was scarcely a metre long. About three inches of this chain remained attached to the base of the upper metal rod. What was left on the bow of the ship was two hooks with a ring between completely deformed, and a little fragment of a link. After the explosion the deck of the *New York* was scattered with globules of iron, which burnt the wood of the deck and the rails in fifty different parts, though at the moment the rain fell in torrents, and there was hail nearly everywhere to the depth of two or three inches.

Franklin stated that in 1787, on his own house in Philadelphia, a flash of lightning had melted a conical rod of copper of ten inches in length and a third of an inch thick at the base, and had volatilised a wire of the thickness of a knitting needle more than six yards long. We could multiply similar narratives.

One curious effect of extreme fusion is that produced by the passage of the atmospheric spark in sandy or moist ground.

Fulgurites, or *lightning-tubes*, discovered in 1711, in Silesia, by Pastor Herman, were discovered afresh in 1805 by Dr. Hentzen, who first pointed out their true origin. These are cylinders or cones, most often hollow, the sides of which are made of vitrified matter, perfectly smooth inside and surrounded outside by a crust composed of agglutinated grains of quartz. Most often the fulgurite is a single tube, which penetrates vertically into the sand, and reaches a length

of ten yards or more. At other times the tube is oblique to the horizon; sometimes also it divides into two or three principal branches, each of which in its turn has small lateral branches, the length of which vary from an inch to a foot.

"The outside crust of these fulgurites," says Arago, "is sometimes rounded, oftenest it has a series of roughnesses very like in aspect to the wrinkles with which the little branches of the elm are covered, or to the cracked bark which clothes the stumps of old birch trees. The irregularities of the vitreous tube correspond to those of the

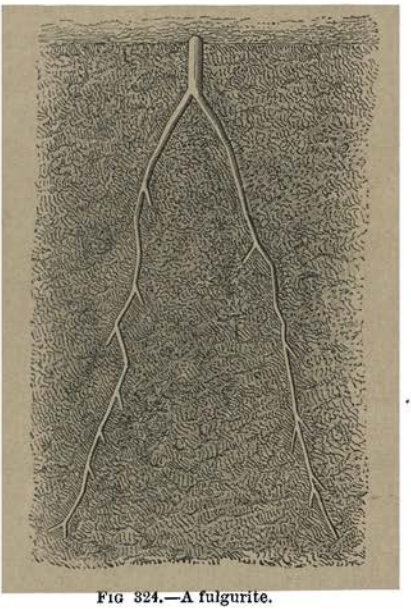

FIG 324.—A fulgurite.

exterior surface; one would say the tube in fusion had been crumpled all along in different directions. When examined through a magnifying-glass the black and white grains which compose the outside crust of the fulgurites appear rounded as if they had begun to be fused." It has been known in many cases that fulgurites are found at the spots where the lightning strikes. In 1823, near a tree which was struck, Professor Hagen, of Königsberg, discovered two narrow, deep holes, one of which contained, at the depth of a foot, a vitrified tube.

On the other hand, tubes like fulgurites have been artificially obtained by discharging strong electric batteries through layers of sand mixed with salt or pounded glass. These experiments have been made in particular by Beudant, Hachette, and Savart, with the aid of the great battery of the *Conservatoire des Arts et Métiers* at Paris.

We have had occasion to remark that lightning acts on the needles of mariners' compasses, the magnetism of which it alters or destroys. This is one of its most dangerous physical effects, at least for the ships struck by lightning, for it may entirely change their direction of sailing by producing an unknown error in the pointing of the compass. We have heard of ships the compasses of which have had their poles reversed, the north being changed to the south; others, which under a similar influence had the needles of their compasses turned permanently to the north-west, the north-north-west, or the south-west. "Towards the year 1675 two English vessels went together on a voyage from London to Barbadoes. Near the Bermudas, lightning broke the mast of one of them and tore the sails; the other received no damage. The captain of the second vessel having remarked that the first turned about and appeared to wish to return to England, asked the cause of this sudden determination, and learnt, not without astonishment that his companion thought he was following the route as at first. An attentive examination of the compasses of the vessel that had been struck showed them that the *fleur de lys*, or arrowhead, which usually stands on the compass-card for the north-pointing pole now indicated the south; so that the poles had been completely reversed by the lightning. It continued in this state during the whole remainder of the voyage."

There is known to be another kind of perturbation produced by lightning, from which no less danger to navigators may result. It is that which results from the magnetising some of the various parts of steel which enter into the construction of chronometers, and particularly of their balances. Thus the chronometers of the packet-boat *New York*, of which we have spoken, were found, on the arrival of the vessel at Liverpool, to be in advance thirty-three minutes fifty-eight seconds on the time they should have indicated if the vessel had not been struck by lightning.

Lightning, which is capable of melting metals or other refractory substances, also excites *chemical combinations* in the air which it traverses. This is easily understood, for we have seen the electric spark produce the synthesis of water in the eudiometer. Liebig found out that rain-water collected after a thunder-storm contained nitrate of ammonia or nitrate of lime in much larger proportion than ordinary rain. From this it is concluded that the nitrogen of the air combines with the oxygen under the influence of atmospheric discharges; it is thought that nitric acid thus formed is the origin of the deposits of saltpetre found in saltpetre caverns. One fact which seems to corroborate this opinion is what has been stated by Boussingault. He remarked that the saltpetre found in America near Rio Bamba is much more abundant in the localities where thunder is frequent.

The strong smell that lightning leaves in places where its ravages have been exercised has been very often compared to that given off by sulphurous substances in burning.

This smell is doubtless of a complex nature, and it is probable that it is composed partly of the smell of ozone, which we have seen to be characteristic of electric discharges, and of other smells, which proceed from organic or other matters in the path of the lightning.

Among these matters it may be that there are some where sulphur is in combination, and which, decomposed by the high temperature of the spark, gives place to the production of sulphurous acid, and justifies the phrase generally used by eye-witnesses; but it is very probable, as Boussingault has remarked, that all unscientific persons would be very apt to describe as "sulphurous" any burning smell accompanied by nauseous odours which they did not distinctly recognise.

Boussingault, when giving an account to the *Académie des Sciences* of the effects of a lightning stroke which had split in two and partly carbonised the trunk of a pear-tree, adds, "This stroke has nothing extraordinary about it, and I should not have mentioned it but for this circumstance: the fire was discovered at four in the morning by a man who went and told the owner of the tree, assuring him that the pear-tree was exhaling an insupportable smell of sulphur. All the people who saw this tree after it had ceased to burn agreed in recognising a sulphurous smell.

"The person who accompanied me then shared and still holds this opinion, for I have not been able to convince him. And yet I can affirm that the very penetrating odour which the burnt parts of the pear-tree gave out, when I examined it, was not at all sulphurous. This smell recalled precisely what is perceived in the manufactories where vinegar is made by distilling wood; there was no mistaking it.

"I have had frequently to do with lightning. A negro was once killed by my side; the house that I inhabited at Zupia was set on fire during a storm; seven times I have seen trees struck in my presence; in Europe, a thunder-bolt fell in my room. Placed so often as I have been in circumstances most favourable for making good observations, is it not astonishing that I have never been able to perceive the smell of sulphurous acid? I think that people generally are too apt to take for sulphurous all penetrating vapours that are necessarily developed every time that an organic body is submitted to the intense heat that may accompany the passage of electricity."

We will finish this section by a summary description of the *physiological effects* of lightning. They are much the most terrible.

Lightning kills or grievously wounds men and animals that it strikes. Sometimes the bodies struck present no apparent hurt; sometimes they show wounds, contusions, or burns in the form of long furrows, where the skin is raised. In the first case, a post-mortem indicates either a cerebral congestion or an effusion of blood in the internal organs. In a word, as Guy Lussac says, the cause of death by lightning is either paralysis of the nervous system or lesion of the organs or of the vascular system. It has been remarked that bodies struck by lightning very quickly tend to become putrified; as indeed frequently happens in cases of sudden death. Is there in this fact a decomposing action belonging to electricity, or this corruption of flesh is it due to the moist heat at the time of the storm? It is said that blood extracted from the veins of bodies struck by lightning has lost the property of coagulating.

It would seem as if some persons are in danger more than others of being struck and killed by lightning. Women would seem to be less exposed than men to it. According to statistics of the victims to lightning in France, gathered by Dr. Boudin, for the period comprised between 1835 and 1863, there were 2,238 killed. Of 880

deaths during the ten last years of that time, there were reckoned only 243 women, or 27 per cent. Is there a special physiological immunity for the feminine sex, or is the difference due to the greater exposure to lightning for men, in consequence of their out-door occupations or their want of prudence ?

Cases have been known of flocks of sheep being totally destroyed by lightning, whilst the shepherd in the midst of his flock was spared. Persons struck are smitten before having seen the flash or heard the thunder. At least, that is what those have said who, having been only knocked down or swooned, have been brought to life again.

After the catastrophe in July, 1819, famous in the records of lightning, which cost the lives of nine persons and wounded eighty-two in the church of Chateauneuf-de-Moustiers, a circumstantial account was sent to the *Académie des Sciences* in Paris; it includes some interesting details, which we shall in part reproduce, on the effects of lightning :—

"On Sunday July 11, 1819, M. Salomé, pastor of Moustiers and episcopal commissary, went to Chateauneuf to instal a new rector. At about half-past ten a procession was formed from the pastor's house to the church. The weather was fine, only some large clouds were remarked. Mass was begun by the new rector.

"A youth of eighteen, who had accompanied the pastor of Moustiers, was chanting the Epistle, when three claps of thunder were heard, which succeeded each other with the rapidity of lightning. The missal was lifted from his hands and torn to pieces; he felt himself tightly nipped in the body by the flame, which afterwards seized him by the neck. Then by an involuntary movement, this youth, who had at first uttered loud cries, closed his mouth, was thrown down, and rolled over people assembled in the church, who had all been thrown down, and forced out at the door. On coming to himself, his first idea was to go into the church again, to the help of the pastor of Moustiers, whom he found suffocated and unconscious. The youth procured for the unfortunate pastor the attention and care of those who, being only slightly wounded, could give him help. They raised him, put out the flames in his surplice, and by means of vinegar recalled him to life about two hours after his swoon. He vomited much blood. He declared he had not heard the thunder, and knew nothing of what was passing. He was taken to the presbytery. The

electric discharge had touched the upper part of the gold lace of the stole, flowed down to the bottom, carried off to the other end of the church one of his shoes, and broken the metal buckle. The seat on which he was seated was also broken.

"The next day the pastor was moved to his own presbytery at Moustiers, to be treated for his wounds, which were not healed till two months after. He had a scar of several fingers' width on his right shoulder; another extended from the right elbow to halfway between that and the wrist; a third deep scar on the left arm, beginning half-way between the elbow and the shoulder, and extending half-way between the elbow and the wrist; a fourth, more superficial and of less extent, on the outside of the lower part of the left thigh, and a fifth on the upper lip up to the nose. He was plagued with absolute insomnia for nearly two months; he had an arm paralysed,[1] and suffered from the various changes of the atmosphere."

"A young child was taken from its mother's arms and carried six paces off. It was only brought to itself by making it breathe the open air. All present had their legs paralysed. All the women, dishevelled, offered a horrible spectacle. The church was filled with thick black smoke; objects could only be distinguished by the flames of the articles of clothing kindled by the flash.

"Eight persons remained dead on the spot. A girl of nineteen years old was carried home unconscious, and died the next morning, a victim to the most horrible suffering, to judge by her howlings; so the number of people killed was nine; that of the wounded was eighty-two.

"The officiating priest was not killed by the lightning, doubtless because he wore a silken vestment.

"All the dogs in the church were found dead, in the attitudes in which they were previously.

[1] It is curious to see that lightning in certain cases causes paralysis, in others heals this same affection. Daguin cites the two following facts:—"In 1762, in Kent, a clergyman, Winter, having been paralysed for a year after an attack of apoplexy, saw a thunderbolt fall in his room, and received a violent shock, after which he found himself radically cured. In August, 1819, at Niort, an invalid, who had suffered for many years with rheumatism in the left arm which made him suffer very much, saw his malady disappear not to return after he had been thrown down by a lightning stroke."

"A woman who was in a cottage on the mountain of Barbin, west of Chateauneuf, saw three masses of fire fall successively, which seemed as if they ought to have reduced the village to ashes.

"It appears that the lightning first struck the cross of the steeple, which was found planted in a crack in the rock at 16 metres distance. The electric fire then penetrated into the church by a breach that it made in the roof, half a metre from the hole where the cord of the bell passes. The pulpit was smashed. An excavation was found in the church of half a metre in diameter, extending under the foundations of the wall up to the pavement in the street, and another which went under the foundations of a stable which was underneath, wherein were found five sheep and a foal dead.

"The bells were ringing when the thunderbolt fell on the church."

Most of the mechanical, physical, and physiological effects of lightning above mentioned are found occurring together in the remarkable event the recital of which we have given. The narrator attributes to the insulating clothing which the celebrating priest wore his preservation from being one of the victims; it is possible that this may be the reason of the fact, as also that lightning is attracted to persons wearing metal objects, which are good conductors of electricity.

But we must not forget that authentic facts are found to contradict these suggestions. Clothing of insulating substances does not suffice to preserve those who wear it; lightning besides often passes between the surface of the body and the objects with which it is covered, as if it found in that thin layer of air, rendered moist by perspiration, a more easy passage.

On the 20th March, 1784, lightning struck the theatre at Mantua, killed two spectators and wounded ten out of about 400 that the place contained. The following curious fact was observed, that the electricity melted ear-rings and watch keys, even split diamonds, and all this without wounding in any way the persons who wore these various things.

The singular, extraordinary, and unusual facts found in the history of lightning are without doubt difficult to explain, because a scientific explanation would require a knowledge of all the circumstances relative to the physical state of the medium and the objects found there, a condition always impossible to fulfil; but none

of these facts are really in contradiction with the known properties of electricity. The conditions of free passage for the fluid through conductors of sufficient size for the flow to take place without any destructive results; the opposite conditions, where it meets resistance endangering the interposed bodies, are in their nature too complex and too variable to be analysed in all details. Also the science of electricity was not built up by proceeding from the observation of the electric phenomena of the atmosphere to the experiments of the laboratory. It is the opposite path that must be followed; and we know that it is that which in reality has been followed.

§ 4.—*St. Elmo's Fire.*

The storms that are properly called *electric storms* are the true dramas of the atmosphere, which in their place have their prologue, their various acts and interludes, and their conclusion. We say nothing here of their manner of origin; that is a point of great meteorological importance, but foreign to what we have to say here. Now besides the phenomena of storms thus defined, atmospheric electricity gives place to other phenomena not less interesting than the lightning stroke.

The ancients had observed them. Cæsar, in his *Commentaries*, relates that during a stormy night the iron of the javelins of the Fifth Legion appeared on fire. Seneca, Livy, and Plutarch relate similar facts, which were then considered as prodigies, or omens from the gods. When a luminous brush appeared alone at the end of a rod or of a ship's mast, it was a threatening sign: it was then called *Helen*. If two flames showed themselves at once, they predicted to the navigators fine weather and a fortunate voyage: they were then the *Twins*, or *Castor and Pollux*, the tutelary gods of navigation. At the moment when the fleet of the Lacedemonian general, Lysander, went out from the port of Lampsacus to give battle to the Athenian fleet, Plutarch relates that on the two sides of the galley which carried Lysander two fires were seen that they called the stars of Castor and Pollux. Amongst the sailors of the Middle Ages, and indeed of these modern times too, the superstition was changed; it

was then the body of a saint, Saint Elmo, surrounded by lighted candles, that thus made an apparition on a ship, presaging the disappearance of the tempest.

The luminous brushes that are seen in stormy weather escaping from the salient points of objects, particularly from the metallic parts, are in every way analogous to those that Franklin was the first to observe at the ends of metallic points presented at a certain distance

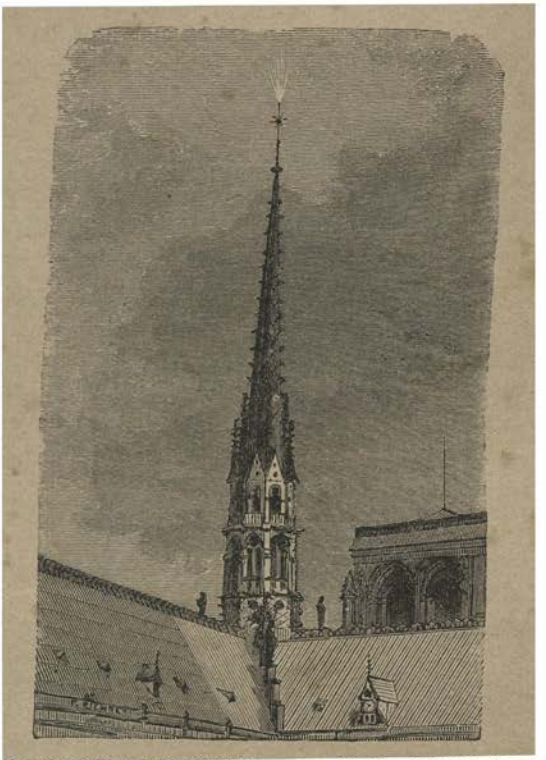

FIG. 325.—Saint Elmo's Fire on the tip of the cross on the church of Nôtre Dame in Paris.

to the conductor of an electric machine. Numerous and curious examples are cited of this silent discharge of the electricity of the atmosphere. We will borrow some from Arago's notice, *Sur le Tonnerre:* "On the 25th of January, 1822, during a great downfall of snow, M. de Thielau, who was going to Freyberg, remarked on the road that the extremities of the branches of all the trees had lights. The colour was slightly blue." "On the 14th of January, 1824, at the

end of a storm, M. Maxadorf, whilst looking at a cart laden with straw, which was under a heavy black cloud in the middle of a field near Cothen, observed that all the slips of straw stood up and seemed on fire. The driver's whip also threw out a bright light. This phenomenon disappeared as soon as the wind had taken away the black cloud. It had lasted ten minutes." "On the 8th of May, 1831, after sunset,

FIG. 326.—Saint Elmo's Fire on the masts and spars of a ship.

some artillery officers were walking with uncovered heads during a storm on the terrace of Fort Bab-Azoun at Algiers. Each one, on looking at his neighbour, remarked with astonishment that the ends of their hair stood up, with little luminous plumes. When these officers raised their hands, plumes of light formed at the ends of their fingers."

During great storms, drops of rain have been seen to become luminous at the moment of touching the ground; sleet and snow-flakes have sometimes presented the same phenomenon.

§ 5.—*Hail.*

If all philosophers do not agree on the origin or the causes of the formation of hail, it is incontestable that it originates from storm clouds when the electricity of the atmosphere is most strongly developed. "It is sufficient," says Arago, "to follow for a few instants the movement of an atmospheric electrometer at the approach of hail to see that electricity changes then very frequently, not only in intensity, but also in its nature; it is not rare to see in these circumstances the passages from positive to negative, and from negative to positive, repeated ten or a dozen times a minute."

It is in spring or summer, and most often during the day, that the most abundant falls of hail take place. Nevertheless it is not rare for it to fall in the night or at dawn. The aspect of hail clouds differs from ordinary storm clouds by a very decided shade of gray; their edges are clean-cut, and their surface presents irregular protuberances; they seem swelled out. One circumstance which has been frequently observed is that these clouds are collected by opposite winds blowing with violence from two opposite points in the horizon. Hail clouds are not at all high up. "More than once," says Arago, "we have seen clouds, from which a few minutes after hail escaped in torrents, cover like a thick veil the whole extent of a valley, while the neighbouring hills enjoyed at the same time a clear sky and a mild temperature."

A few instants before the fall of a heavy shower of hail you may hear in the cloud a singular noise, a sort of crackling, that has been compared to that of a cart rolling on pebbly ground, or like the noise of a sack of nuts that is being moved or emptied. This precursory sign, which country people recognise as well as meteorologists, is sometimes so loud that it prevents thunder from being heard. At the approach of a storm, Peltier, being at the time at Ham, heard so much noise that he thought a squadron of cavalry was arriving at a galop on the square of the town. There was nothing of the sort

but twenty minutes had scarcely passed when a frightful downpour of hail came to explain the phenomenon.

The eminently electric character of hailstorms does not rest only on precursory signs such as those of which Arago spoke. Innumerable discharges are produced in the interior of storm clouds between the superposed layers brought together by opposite currents mentioned above. On the 7th of May, 1865, a hail storm devastated the valley of l'Escaut; an engineer, M. Lermoyez, described this in a note addressed to the *Académie des Sciences*, wherein we read the following: "At three o'clock large clouds forming superposed layers showed themselves in the south-west, and very soon thunder was heard. Above them rose up a thick cumulus cloud of a livid white, in which was produced a *continued artillery of lightning;* underneath, many layers of clouds of dark tints, approaching the sun, constituted a wide base for this sort of pyramid. The rolling of the thunder continued, but without intensity or crash; a constant pricking of lightning engendered a sort of continuous crackling, and the explosions seemed to be concentrated in the interior of the largest clouds." Ten years later another storm of hail devastated the valley of the Rhone. Colladon gave the following details of the electric phenomena which accompanied this destructive shower: "These phenomena," he says, "were very remarkable on the central parts of the hail cloud; the flashes succeeded with such rapidity from midnight to some minutes past one o'clock, that on an average two or three flashes per second were counted, which would make 8,000 or 10,000 per hour. Intense phenomena of electric phosphorescence were remarked during and before the hail, on the ground, on animals, on salient objects; the hailstones also were phosphorescent. A very strong smell of ozone was remarked immediately after the hail; most of the observers compared the smell to garlic. But very few thunderbolts fell; incessant electric discharges were made from an upper cloud to the clouds immediately below, whence the hail fell; the detonations heard were very rare."

Such are the principal characters of the phenomenon as a whole. We have yet to deal with the hailstones themselves, which vary from one storm to another in form, size, and structure, but which in the same downpour are generally very much alike.

We will first consider hail with regard to the matter which

constitutes it, the congealed grains, the forms, and varied sizes. Sometimes sleet is confounded with hail. And yet even from the first, between these two aqueous and solid products that the atmosphere sends us, there is this difference—that it is in spring, the time of showers, that sleet falls, and the squalls from which it proceeds are rarely of the electric character of true hailstorms. And, again, besides their relative smallness, the grains of sleet are opaque, of a dull white, which makes them look as if powdered with flour; their form also is more often a polyhedron, or a pyramid, than a sphere.

The structure of hailstones differs decidedly from that of sleet. The resemblance consists in this, that in the centre of a hailstone

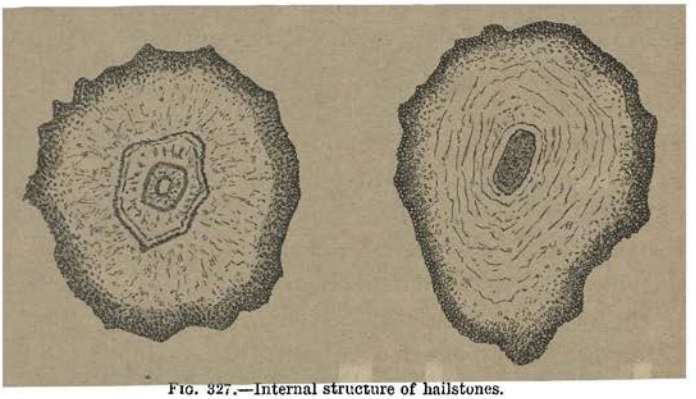

FIG. 327.—Internal structure of hailstones.

there is almost always an opaque part, that looks like a little lump of snow, or a grain of sleet.[1] But this spongy kernel is enveloped by a series of layers of transparent ice. Sometimes the layers we speak of are alternately clear and opaque. The following is Colladon's description of the hailstones he gathered during a storm on July 7, 1875, and which we have before mentioned:

"The size of the hailstones varied from 10 to 30 millimetres, the greatest diameter was from 60 even to 100 millimetres; the weight of many, six hours after the fall, was more than 300 grammes (over half a pound). All the hailstones had in their centre a kernel

[1] [In many well-authenticated cases small particles of stony matter have been found as the cores of hailstones. In some cases these stony particles have been proved to contain—like meteorites—a considerable proportion of iron.—ED.]

of sleet varying from 5 to 10 millimetres in diameter. This kernel was surrounded by concentric layers alternately transparent and opaque; on an average these were 6 or 8, the last two being decidedly thicker, the last opaque and rough.

"The large hailstones, for the most part, were flattened. These were compared in many places to slices of citron, and flat or lenticular as they were, they evidently did not come from large hailstones broken."

From this example we see what considerable size and weight hailstones do sometimes attain. We might quote many other examples from witnesses worthy of belief, that is to say, accustomed like M. Colladon to precision in observations and measurements.

On the 29th of April, 1697, there fell in Flintshire hailstones the weight of which Halley gave as 150 grammes. Parent, of the *Académie des Sciences*, saw in May, 1703, in le Perche, hailstones fall the size of his fist.

Volta declares that in a storm which burst in August, 1787, on the town of Como and its suburbs, hailstones fell the size of a hen's egg, weighing 280 grammes.

Now, is it true that in 1829, a hailstorm which ravaged Cazorta, in Spain, gave blocks 2 kilogrammes in weight? Is it necessary to believe the tale of a missionary, M. Hue, who declares that he saw fall in Mongolia, hailstones that weighed 6 kilogrammes (13 pounds)? Is it likely that in 1843, during a great storm, there fell in a field a piece of ice bigger than a millstone, which was broken with hatchets, and though it was in the hottest weather, it was three days before it was entirely melted?

It is not impossible that such blocks may have been seen after a storm of hail; but what was taken for a hailstone, was without doubt an agglomerate of a multitude of grains united together after the fall. Here are some facts which authorise this interpretation. "On the 11th of July, 1753," says Arago, "Montignot picked up at Toul hailstones which had the form of irregular polyhedrons, of nearly *three inches* (8 centimetres) in diameter every way. These large hailstones were an assemblage of smaller hailstones which had become adherent together before falling." Lermoyer, whom we have already cited in connection with the hailstorm of May 7th, 1865, thus expresses himself on the dimensions of hailstones: "At Vend-

huile," he says, "they were the size of a bullet; at Catelet, they reached the size of pigeons' eggs, and even hens' eggs: but, on attentively examining these latter, we recognised that they were only an agglomeration of very small hailstones, easily distinguishable."

Up to the present we have only spoken of grains that have doubtless been united before falling, but we find further: "The most extraordinary fact was the incalculable quantity of hail that fell at Vendhuile and Catelet.

"A small side ditch of the canal of Saint Quentin, which serves to drain 500 hectares (1,250 acres) of land, received so much water and hail, that the flood mounted over the high embankments of the canal, swept before it a heap of 800 hectolitres (2,800 cubic feet) of coal, with which it precipitated itself into the bed of the navigable canal, which it obstructed in the most complete manner. I observed the day after the storm that this deposit of hail, extending over the length of 462 metres (500 yards), and a width of 20 metres (22 yards), presented at certain points a height exceeding 5 metres (5½ yards); it formed thus a volume of more than 40,000 cubic metres (53,000 cubic yards), so compact, that the water up the river, though raised 2 feet above the water down the river did not fall a millimetre in twenty-four hours. This deposit constituted a veritable glacier, on which we could walk without the least danger. When I succeeded in making a cutting in it to establish a current which would take it away, it became detached in considerable masses which floated in the water like icebergs."

This last phrase of the learned engineer's account will, we think, help us to understand that the hailstone which fell in Mongolia, and which according to Hue, was as big as a millstone, was after all an agglomeration of hailstones which became adherent after falling.

A word now on the form and structure of hailstones. We have already seen that there are some of the form of a pyramid, terminated by a curved base or a spherical sector; are not these fragments of hailstones having their first form of a sphere? An observation of the geographical engineer, Delcros, makes this probable. In a storm in July, 1819, he picked up "several of these hailstones, in which could be seen a spherical kernel of an opaque white, showing traces of concentric layers; an envelope of compact ice, with rays from the

centre to the circumference, and terminating outside by a dozen great pyramids, between which smaller pyramids were intercalated; the whole forming a spherical mass of nearly nine centimetres in diameter."

Another curious form of hailstones is that of a round mass, roughly

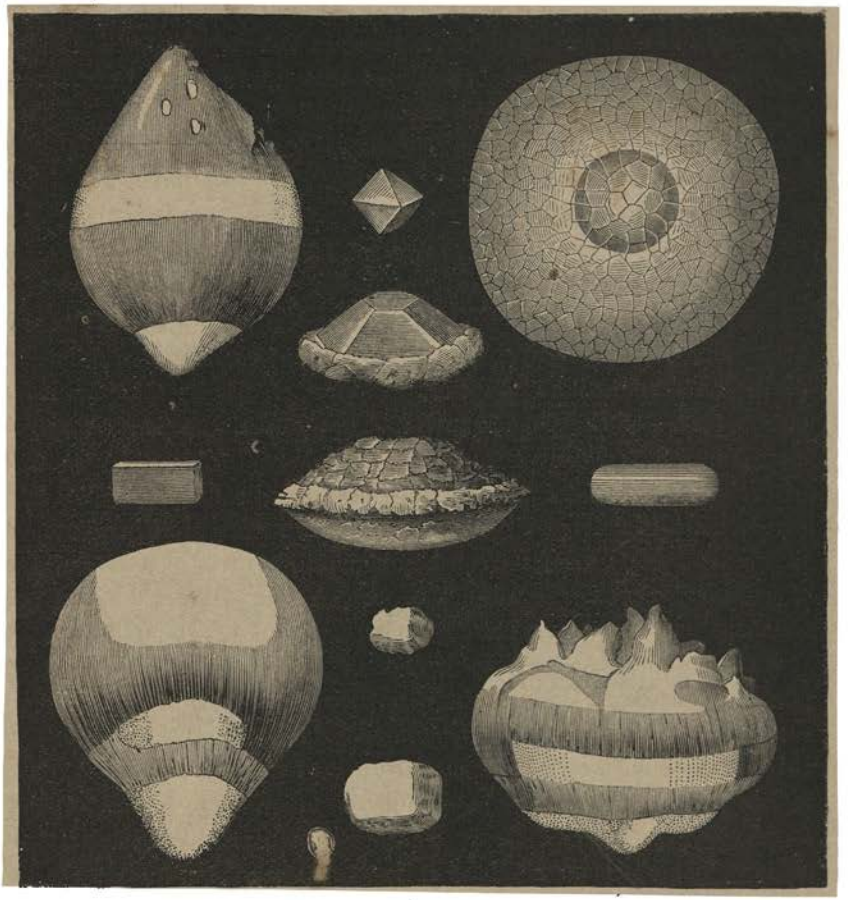

FIG. 328.—Various forms of hailstones.

spheroidal, but surrounded with asperities or points, giving to the hailstones the aspect of spiny pebbles. The terrible storm of hail which extended its ravages over the whole extent of France, and even into the Netherlands, on the 13th of July, 1788, furnished stones of this singular form, elongated and armed with points. We have seen hai-

stones at first having the form of pyramidal sectors with six sides, then in the same storm, the direction of the wind having changed, they fell in the form of plano-convex lenses, so transparent and so regular in form that they served as magnifying glasses, enlarging objects without disfiguring them.

We have described the principal characters of hailstones, and the aspect of the phenomena as a whole and in details. It remains to us now to show the principal hypotheses that up to the present time have been suggested to explain these facts.

§ 6.—*Theory of Hail.*

Is there a theory of hail, based on the analysis of facts, in accordance with the principles of physics, susceptible, in a word, of giving an account, like the theory of dew, of all the characteristic circumstances of the phenomenon? That is the question for us to examine.

Volta is without contradiction the first who tried to solve the problem in all its perplexity; but the earlier attempts, incomplete as they are in explaining the phenomena, still offer a certain interest of curiosity, because there are the germs of many ideas adopted by the meteorologists of this century. We will quote some of them.

Musschenbroek attributed the formation of hail to *congealing particles* which, contained in the air in certain circumstances, freeze the drops of rain. What are these congealing particles, and in what circumstances do they float about in the air? Upon this the philosopher says nothing. Perhaps he has taken his opinion from Descartes' *Traité des Météores.* That great philosopher was so little able to apply observation in the scientific theories that he supported that, in order to explain hail, he was obliged to imagine a form of clouds, of which he had certainly not confirmed the existence. He supposed that "the clouds where hail was formed were composed of very small particles of snow or ice which partly melted and then united, a cold wind at last freezing them; at other times the snow melts totally, and then the wind must be very cold to convert the drops of water into hail." De Ratte, in reporting this hypothesis of

Descartes in the *Encyclopedia*, declares it untenable in its totality, and this is the reason he gives: "Everybody now knows," he says, "that clouds are not masses of ice, but mist, like what we so often see rising and spreading over the surface of the earth."

Now, however, balloon ascents have proved that Descartes was right, not in his theory of hail, which is obviously very insufficient, but in the fact of the existence, even in the height of summer, of clouds formed of particles of ice. It is curious to see that what now is proved true in this hypothesis is precisely what was rejected in the last century. It must be said that Descartes' theory is that given now for the formation of sleet.

The difficulty for philosophers a century ago was to comprehend how it could happen that, at the relatively small height of storm clouds, it was in summer cold enough to congeal masses of water as large as hailstones. Descartes had supposed a cold wind, without indicating its origin. Hamberger's explanation was scarcely admissible; according to him, "When the upper part of a large cloud is directly opposed to the rays of the sun, and that the lower part is in the shade, the latter becomes so cold that all the drops of water which compose it are converted into ice." De Mairan supposes that there was evaporation, which, as we shall see, plays a great part in Volta's theory. The author of a mémoir, which in 1752 was awarded a prize by the Academy of Bordeaux, had recourse, in order to explain the congelation of hailstones, to the cold which results from the mixture of certain chemical substances. "Hail," according to him, "is a mixture of iced water, ammonium chloride, rock-salt, and sulphur. It is the result of an artificial congelation like what we make every day by means of salts." De Ratte, who finds that there are in the arguments of this author "very ingenious ideas," accepts this curious hypothesis; he adds the effect of evaporation, which he does not confound with that of a cold wind; then he explains at some length the influence of atmospheric evaporation on the formation of hailstones and the development of electricity.

All these conjectures are now obsolete, and scarcely merit the name of theories. A theory worthy of the name was then impossible. Precise observations there were none. We have said we must go back to Volta to find a theory of hail founded on exact observations, and resting on any scientific reasons. As he formulated it, it is far from

being free from objections, and there have been very serious ones made to it; but it forms an entire whole, and it still claims some partisans, who think themselves authorized to persist in their ideas because no theory so complete and harmonious has as yet been proposed to replace it.

The following is the substance of this theory:—

Two principal parts may be distinguished in it: one, the object of which is to assign an origin to the intense cold necessary to form hailstones; the other to show how the hailstones, once formed, are supported a sufficiently long time in the air to acquire the enormous size that numerous observations have so frequently confirmed.

The first cause, that of cold, is active evaporation: the second, that of the suspension and increase in size of the hailstones, is the electricity of storm-clouds. By referring to these two causes the circumstances known about the origin of hailstorms, Volta was enabled to give an account of all the details of the phenomena. Let us see how he solved this complex problem; we will examine afterwards whether the solution is tenable or not.

Let us suppose, in the middle region of the clouds, a cloud exposed during a warm summer's day to the solar radiation. According to repeated observations of Deluc and Saussure, the air surmounting this cloud is, under those circumstances, and at a certain hour of the day, in a state of extreme dryness. The evaporation of the upper surface of the cloud, favoured by the double condition of the great intensity of the sun's rays and the dryness of the surrounding medium, will then be very active; but according to Volta it is also favoured by another cause, and here electricity begins to intervene. The clouds being considered as formed of little vesicles, hollow,[1] with a liquid envelope, are in a very elastic state; the least cause tends to reduce them to this state; now storm clouds are charged with electricity, and the experiments of physicists show that the evaporation of an electrified liquid is more rapid than that of a liquid in a neutral state.

So, for all these reasons, there is rapid and abundant evaporation. Hence a considerable cooling, which, reaching the particles not

[1] [English physicists do not now consider cloud or mist to consist of hollow vesicles, but of minute solid spherules of water which are continually forming and falling through the air, evaporating and re-forming.—ED.]

vaporised, congeals them, transforming them into flakes of snow, embryos of future hailstones.

The kernels of hailstones once being formed, the increase in size remains to be explained. Up to the present, it is but a flake of snow, or a grain of sleet, as we have seen, that hailstones mostly have in their centre. Before Volta's time the increase of the dimensions of hailstones had been attributed to successive congelations of the aqueous particles they meet in their fall, congelations due to the very low temperature of the kernel. But it is difficult, even impossible, to admit that a hailstone, which at first is never bigger than a pea, could increase to acquire the size of a nut, or a hen's egg, during the necessarily limited time of its fall. As Arago well remarked, "the storm clouds are almost always very low, and certainly hail coming from them would not take more than a minute to fall to the ground. Volta thought it necessary to suppose that hail already formed, remained suspended in space, not only five, ten, or fifteen minutes, but perhaps even whole hours." But what is the cause of such a prolonged suspension of a body whose weight would precipitate it to the ground? Here is the answer: Volta relied on the simultaneous existence of two superposed clouds; the lower is the storm-cloud, and which he supposes to be formed first. The other would be the product of the vapour accumulated by the evaporation of the lower cloud, carried into the higher regions of the air. The relatively low temperature of these regions condenses this vapour as soon as the air is saturated, and thus produces a second cloud. We have seen in the preceding paragraph that observation confirms, at least in part, the formation of this new storm-cloud; the existence of these strata of superposed clouds has often been demonstrated, and Volta says they are charged with opposite electricity. It happens, exactly as the illustrious physicist himself observed by the aid of an atmospheric electrometer, that the passage from one electric state to the contrary, from the positive to the negative, and *vice-versâ*, takes place in the same cloud in a very short time; he reckoned in a minute, fourteen changes of this kind.

Moreover, the frequent, not to say continuous, discharges that we have seen and observed in hail clouds show clearly the rapidity of these modifications in the electric state.

These points admitted, Volta had recourse to an experiment well

known amongst the old apparatus used with electrifying machines under the name of the "dancing balls" (see Fig. 125, p. 225), and which consists of a perpetual movement backwards and forwards of small bodies, such as pith balls, between two metal plates, one fixed to the conductor of an electric machine, the other communicating with the earth. It is a movement like that which would be produced, by identical causes, between the two strata of storm clouds.

The flakes of snow of the lower cloud, brought by the wind to a state of sleet, possess the same electricity as the cloud, and are repelled by it, and attracted by the upper cloud, the electricity of which they partake as soon as they arrive in contact with it. Then repelled below, they fall again into the lower cloud, and so on continuously. These oscillations last a greater or less time, during which the hailstones increase at the expense of the vesicular vapours which they condense and congeal. In these movements the hailstones knock against each other, and thus produce that singular crackling noise, precursor of their fall. Having become too large, they yield to the action of gravity and fall to the ground.

Such is briefly Volta's theory of hail. We have said that it is not free from grave objections, objections based on facts. For example, a disciple of Volta, Bellani, observed at once that hail could only be formed during the day since the cold which produces it is due to the evaporation caused by the sun's rays. Now there are examples numerous enough of heavy falls of hail during the night. Bellani cited a remarkable one in July 1806, begun before sunrise, during which a prodigious quantity of hail fell, and that no indication had announced the evening before, over the whole extent of the visible horizon.

A more grave objection, and a theoretical one, was made by Arago in these terms :

"The first congelation of clouds results, says Volta, from the evaporation that their upper surfaces experience under the action of solar rays. If this evaporation is at all like that which the wind causes on the earth, a certain degree of cold would be the necessary consequence; but it seems very difficult to admit that the solar radiation or any other heating cause could hasten the evaporation of any liquid whatever without communicating its heat. To warm a body would never be a means of making it cold, by whatever way evaporation might intervene."

We pass over in silence other objections of detail, that Bellani, Arago, Kaemtz, Pouillet, and other philosophers have mentioned in their works, and we will look at another side of the question which seems to have escaped Volta. It is that of the origin of the two groups of clouds, which he explains as being formed one from the other, whilst observation shows them to be independent, animated sometimes even by opposite movements. If it is proved that these two layers of clouds, which determine the fall of hail, have an independent origin, the first part of Volta's theory, well shaken already by the objections before mentioned, would crumble away completely. Now, this is a fact which results from observations.

It appears even, that most frequently it is the highest clouds, the cirri, which are formed first, at very considerable heights in the atmosphere. Now it is known since the balloon ascent of Bixio and Barral, in 1850, that similar clouds may be entirely composed of particles of ice, fine needles interlacing with each other, or flakes of snowy matter. Kaemtz thought that it was in the midst of these clouds, formed in regions with a very low temperature, that we must search for the source of cold necessary for the formation of hailstones. "As the upper layer of cirrus," he says, "becomes more dense, and descends, so the cumulus clouds are formed, which increase with extraordinary rapidity. Then it is that the wind presents opposite directions, resulting from the unequal subdivision of the clouds in the sky, and from the lowering of the temperature which accompanies their presence." This meteorologist thinks that the action of opposite winds which struggle against each other, and the ascending whirlwinds that result have a great influence on the condensation of lower aqueous vapours, and on the accretion of hailstones.

We come now to an hypothesis which very much resembles the conjectures of Kaemtz, but which is more clearly formulated.

We speak of the new theory of hail proposed by M. Faye.

This theory is based on the following considerations, which we sum up in their fundamental details.[1] Faye asks what are the essential characteristics of storms where hail can be formed, and he finds that they are reduced to three: 1. Strong electric charge of the clouds, which in ordinary weather are in a neutral state;

[1] *Comptes Rendus* of the Academy of Sciences, 1875.

2. Formation of enormous masses of ice in clouds situated at a height, where there is generally a temperature much above zero; 3. Extraordinary rapidity with which the hail clouds are displaced.

These three points established, enormous quantity of movement, continued production of ice, electric condition unceasingly renewed, "shall we look for the origin," asks Faye, "in the lower regions, in the ascending currents formed, we know not how, in the midst of the lower layers of the atmosphere? If we do, the problem of storms will remain insoluble; for in these lower regions reign: (1) a complete calm, (2) a stifling heat, and (3) an electric condition that is insensible." It is then in the high regions of the air that we must seek for the three essential elements of storms. It rests in the first place on this fact of observation, that the electric potential undergoes a continued increase as elevation in the atmosphere increases. "The air of the upper regions is strongly charged with positive electricity, the maximum of which has not yet been observed. The air near the ground is, on the contrary at zero potential, or if it possesses any it is a feeble, negative potential like that of the earth." Faye considers the globe to be enveloped, at a height beyond one or two leagues, by a vast *nappe* strongly electrified, and insulated from the common reservoir by layers of lower air. This covering is continually moving on towards both poles, and it is partly by storms, partly by aurora borealis, that its electricity is discharged to the ground, sometimes with noise, sometimes silently.

In the second place, Faye rests on the fact that we have already mentioned, viz. that of the existence in the middle of summer, in the high regions of the air, of clouds of a very low temperature, formed of fine needles of ice; also on this other fact that cirri are precursors of storms. "If then," he adds, "by any mechanism whatever, the upper air could be brought, with its ice clouds, into the lower region of the nimbus, and that continually and persistently, it would be easy to explain first the formation of these nimbus clouds themselves, then the congelation of their vesicular water, in spite of the high temperature of these regions."

We come now to what constitutes the originality of the theory proposed by Faye. He had already said that besides a source of electricity and a source of cold, a source of movement was necessary to explain the rapid translation of storms. It is to the high regions

also, to the general upper currents which bear the icy cirrus, that we must go to find the third element indispensable in his hypothesis.

It is known that the eminent astronomer has been led to occupy himself with meteorology by his studies on the physical constitution of the sun, the spots of which are due, according to him, to the gyratory movements, or whirlwinds, of which the layers of the solar atmosphere are the constant scene. To answer objections made to him, he was led to study the movements of the same kind of the terrestrial atmosphere: water-spouts, tornadoes, cyclones. Without entering into all the details on this subject, which would lead us too far, we will say that Faye considers whirlwinds due to the inequalities of speed of contiguous layers of air, as having a tendency to propagate themselves from a height downwards, all the more pronounced as the movement of gyration is more violent. Such whirlwinds carry rapidly down all the materials supported by the upper currents, including the frozen cirrus which float there: "The needles of ice, crowded together in the circumference because of their density, meet there and agglomerate so as to form little opaque nuclei. These meeting in the lower clouds with vesicular water congeal it into a thin transparent layer. If, in this whirlwind movement, where the whirling masses centred on the same axis have all varieties of speeds, these little hailstones should pass successively into regions occupied by glacial air from above, and into others filled with vesicular vapours, they will increase in volume by successive layers, till they escape by their weight, or by centrifugal force, or by the action of the whirlwind." "The air drawn below will not bring the needles of ice alone, it will also bring strong electric charges. These will accumulate progressively on the surface of the cloud situated at the end of the whirlwind, and will soon acquire a potential sufficient to escape in lightning-flashes towards the neighbouring clouds, and finally towards the earth."

Such is the solution proposed by Faye: it is absolutely different from Volta's electric theory of hail. For the cold produced by evaporation, Faye substitutes a mechanical transport of chilled layers from the high regions; as for electricity, he does not consider it to be a producing cause of hail. The increase in size of hailstones is by him attributed to the oscillating movements of the nuclei in vapourous clouds, but it is not electric attraction and repulsion, it is

a purely mechanical action, that of the whirlwind movement, which explains the prolonged suspension of the flakes of ice.

A learned French meteorologist, Renou, thinks that the temperature of hail clouds may be very low—even to 22° below zero—without the vesicles of the clouds ceasing to be in a liquid state. Such a state is eminently unstable; it is known that the contact of a very small crystal of ice is sufficient to cause water in a state of surfusion to congeal spontaneously: hence the beginning of hailstones. Rosenthiel, who observed at Mulhausen, in 1872, some large hailstones, the structure of which indicates immediate crystallisation, thinks that such crystals proceed from congelation in a medium in the state of surfusion; but he thinks that the theory of Faye explains very well the presence of other crystals which determined congelation in the whole medium.

These different theories are alike in one point; they all exclude the intervention of electricity, so manifest however, at least in appearance, in all hailstorms. But they are far from having the assent of all philosophers, and the electric origin of hail is still considered as possible. On the other hand, Volta's theory appears as if it should be modified in some essential points. Accordingly Colladon, resting on very precise observations, does not admit that there are only two clouds in presence, placed one above the other at a great distance, and between which the hailstones mount and descend.

According to him, "these stormy groups are composed, in reality, of a great number of electric centres, close together, though quite distinct, and able to meet in many different ways. The theory of the formation of hail, he says, becomes then much less problematic; the hailstones are tossed about, and attracted towards one of the centres, then towards another, by the effect of their enormous positive or negative charge; in these successive oscillations, hailstones envelop themselves alternately with drops of iced water, or needles of ice and sleet. The speed of oscillation would decrease as the hailstones became bigger, and acquired more weight; this well accounts for the increasing thickness from the centre to the circumference of the successive layers which surround the grain of sleet in the middle of the hailstone. Besides, it is easy to conceive that, during the time that the hailstones are thus suspended in the

midst of the clouds, and strongly electrified, many of them provided with protuberances may take a gyratory movement as electric whirls do; they would increase more rapidly in the plane of rotation, and would finally acquire the form of flat and regular hailstones, like those which fell in great numbers on the 7th of July, 1875.

We will finish this paragraph by a short account of an electric theory of hail due to Planté, and of which the point of departure is an experiment in the laboratory made by this accomplished physicist.

When you discharge a battery of four hundred secondary cells at the surface of a liquid, you see issue a sheaf of aqueous globules of an ovoïd form, which succeed each other with excessive rapidity, and are projected a distance of more than a metre from the vessel where the experiment is made. In Planté's mind the phenomenon which is produced then is the image of what passes in the midst of hail clouds. "The clouds," he says, "are not, it is true, liquid masses properly so called, but those of high regions are composed, as is well known, of very fine light crystals of ice, the cohesion of which is less than that of ordinary ice, and which may be considered as equivalent, or nearly so, to a liquid mass suspended in the air. It may be conceived then that electric discharges may produce there an effect analogous to that which they produce on a liquid, and that the water of these crystals of ice, liquified and finely divided at the points where the discharges escape, would be thrown up in sheaves of globules, as in our experiment. Again, by reason of the low temperature of the whole cloud, itself, or the elevated regions in which the phenomenon is produced these globules may be instantly congealed and thus cause hailstones." In short, Planté considers hail as resulting from the congelation, in the high and cold regions of the atmosphere, of the water of the clouds, finely divided and pulverized by electric discharges. To explain the structure of hailstones formed of alternate opaque and transparent layers, he supposes many successive vaporizations and congelations, separated by intervals when the hailstone undergoes a gyratory movement. "The opacity of the snowy nucleus which forms these hailstones seems to show a sudden seizing and congelation of the vapour of water; for it is known that it is the character of rapid crystallization to form entangled crystals which are not transparent. The first nucleus formed, gyration in the midst of the

humidity of the cloud would produce round it a layer of ice, very slowly formed, and in consequence transparent. After a fresh electric discharge another emission of vapour takes place, and at the same time fresh hailstones result; those which still turn can cover themselves with a second layer of vapour, which quickly congeals to the snowy state, and so on."

§ 7.—*Water-spouts and Tornadoes.*

Among the number of phenomena which appear to have more or less relation to atmospheric electricity, are ranged whirlwinds, a kind of vortex which is formed between the clouds and the earth; they may be divided into two categories, according as they are produced over the sea, or over the land, viz. *Water-spouts* and *Tornadoes*.

We will first give a summary description of the phenomena which characterize both kinds of vortices. The learned director of the Observatory of Paris, Admiral Mouchez, a few years since, thus described the circumstances under which marine water-spouts are usually produced. It is at the lower edge of a thick and very low nimbus that they generally begin, during a dead calm or very faint breeze. If there is only a moderate wind it dissipates them nearly as soon as formed. In general the sky is in some points of the horizon clear, in others covered with very heavy clouds, which surmount much clearer tufted masses. "When these circumstances present themselves," he says, "with others as yet unknown, you may see, at the lower part of the cloud, a protuberance form which slowly descends towards the sea, and takes the form of a column or tube, which remains vertical, if it is an absolute calm, and undulates slightly if there be any breath of wind. When this tube, the upper part of which is always enveloped in a second more nebulous tube or sleeve, has reached about four-fifths the height of the cloud, you may see the surface of the water begin to boil up slightly right below the water-spout if it be vertical, or in an oblique direction, making the angle of reflexion equal to an angle of incidence, if the waterspout is inclined. Whilst this emission of vapour or water takes place, the tube becomes more and more clear, and finishes by appearing only in the form of two black very slender traces. When the jet of vapour ceases, the

water-spout seems to have finished its work, for it begins to dissolve at the lower part and to mount again towards the cloud, in which it soon loses itself.

"Sometimes, instead of one tube only, you see two or three, one inside the other, all perfectly concentric, regular, and always limited by very clear outlines.

"The fineness and clearness of these black lines is a very curious and very characteristic fact. It happens frequently that the axis itself is marked by a central line prolonged beyond the tube down to the sea."

FIG. 329.—Formation of a water-spout at sea

Frequently several water-spouts have been seen coming from one cloud, some dissipating before their complete development, others uniting to form one. Sometimes the column is divided in the lower part, allowing its contents to escape into the sea in the form of a jet or sheaf of liquid. Dr. Bonafons observed on the coast of Algiers the inverse phenomenon. The column descending towards the surface of the sea, the water rose as if attracted to meet it; immediately that contact took place "an ascending motion, like that in a siphon when the vacuum has been made, was set up inside the column. The movement, which we saw distinctly, was made

in a spiral, in the form of a sucker, from its vertex to its base, which could not be distinguished from the cloud. This spiral, in which the ascending rapid current of water was seen, followed the dimensions of the waterspout, which was very narrow in the lower part, but larger higher up. Having arrived at the higher part, the mass of water appeared to become rarefied in order to mix itself with the cloud, which visibly increased."

Water-spouts have been seen which, instead of beginning at the top, had their origin below (Fig. 328). Such is the case with a water-

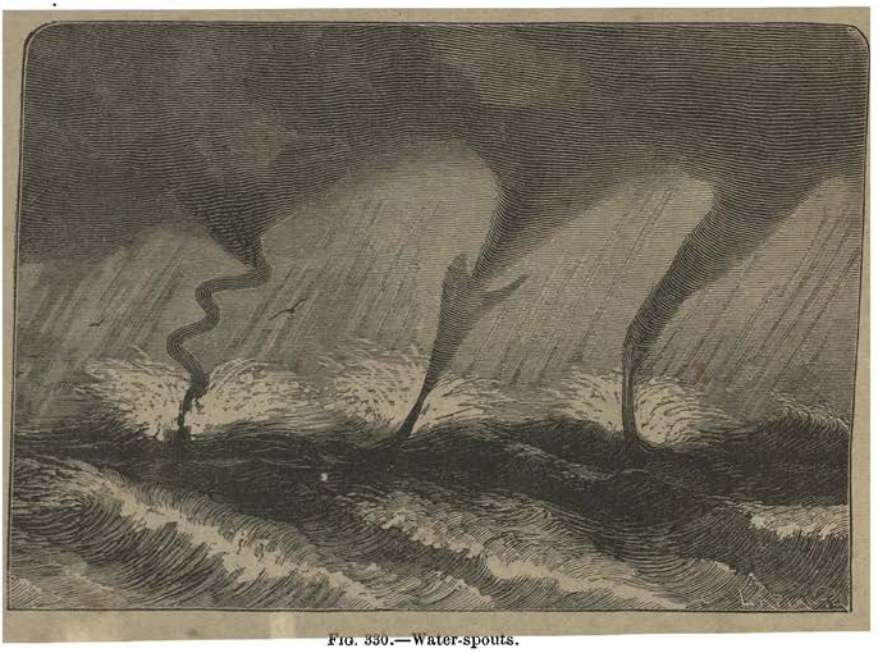

FIG. 330.—Water-spouts.

spout observed in 1864, in the Gulf of Bougie, by Lieutenant Leps: "A whirlwind was perceived on the surface of the sea; the water was thrown up to a very considerable height, then ever rising and whirling, it went to join a large black cloud."

Clouds which produce water-spouts are often scored with lightning flashes, accompanied with thunder-claps, particularly at the moment of the formation of the descending column; but this is not a general phenomenon, and it often happens that water-spouts form and pass away without a sign of the electricity in the clouds whence they

proceed. Cases are cited wherein the lightning occurred after the disappearance of the water-spout; this happened with the double water-spout observed in April, 1826, on the coast of Florida, by Dr. Lincoln. Cook, after describing many water-spouts that he had observed in 1774 at the south part of New Zealand, says that after the disappearance of the last waterspout there was lightning without thunder.

Marine waterspouts are rarely dangerous, in the first place because they occupy a very restricted space and sailors easily avoid them; in the second place, because many of them proceed from whirling movements of no great importance. Cases are, however, known of waterspouts having come into contact with ships, and have caused them serious damage.

Terrestrial vortices, happily much less frequent than marine ones, are generally more disastrous. You may judge by an example; the tornado which on the 18th of June, 1839, ravaged the parish of Châtenay, in the department of Seine and Oise, we have chosen from amongst many others. The account of it is borrowed from Peltier's *Traité des Trombes*:—

"In the morning a storm began from the south near Châtenay, and towards ten o'clock it moved into the valley between the hills Ecouen and the little mountain of Châtenay. The clouds were tolerably high, and after extending themselves over the eastern extremity of the village they stopped; thunder was heard, and this first storm followed the ordinary course, when towards midday a second storm, coming also from the south, and proceeding very rapidly, was directed towards the same plain and the same hill. On reaching the extremity of the plain above Fontenay, in the presence of the first storm, which dominated it from above, its motion ceased: doubtless the clouds of both the storms were charged with similar electric charges, which consequently set up a mutual repulsion.

"Thunder had already been heard in the second storm, when suddenly one of the lower clouds descended towards the earth, put itself in communication with it by forming a sort of inverted cone, having its base in the upper clouds and its apex at a few yards from the earth. This apex terminated in a fiery cap of a vivid red colour. At this moment all detonations ceased. A prodigious attraction took place; all the dust, all the light bodies which covered the

surface of the soil were attracted to the point of the cloud; a continued rolling and confusion was heard; small clouds fluttered and whirled about round the inverted cone, mounting and descending rapidly. The trees standing at the south-east of the water-spout were attacked on their north-west side, which was opposite to it; the other half of them was not hurt, and preserved their usual condition. The parts attacked sustained heavy damage, of which we shall speak hereafter, whilst the other parts preserved their sap and their foliage.

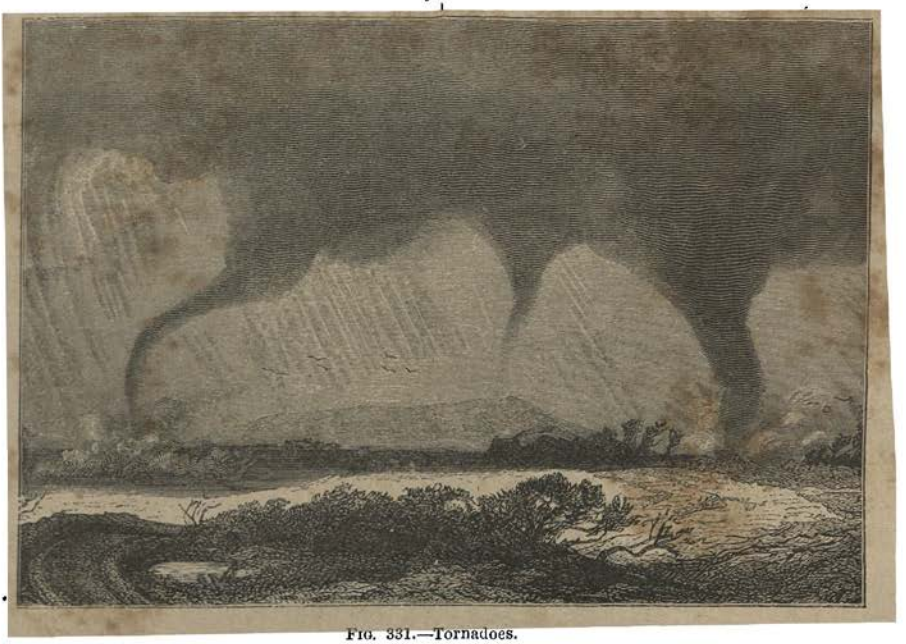

FIG. 331.—Tornadoes.

The tornado came down into the valley at the end of Fontenay, near some trees planted along a damp waterless ditch, then, after having broken and uprooted everything, it crossed the valley and advanced towards other plantations of trees, that it also destroyed. There the tornado stopped some minutes: it had arrived under the edge of the first storm. The latter, which until then had been stationary, now began to move and draw back towards the west valley of Châtenay. The tornado, having dried up and destroyed the plantation of Thibault, went on, overthrowing everything in its path, towards the

park of the Chateau of Châtenay, which it transformed into a scene of desolation. The youngest trees alone, situated at the end of the park beyond the cyclone, were the only ones which remained. Walls were thrown down; the chateau and the farm lost their roofs and their chimneys; trees were carried away some hundreds of metres distant; boards, rafters, and tiles were projected 500 yards and more.

"The tornado having ravaged everything, descended the hill towards the north, stopped over a pond, overturned and blasted half the trees, killed all the fish, and advanced slowly along a row of willow trees, the roots of which extended into the water. Here it lost a great part of its size and its violence. It proceeded more slowly still along a plain situated near; then about 1,100 yards further on, near a clump of trees, it divided into two portions, one of which rose into the clouds, the other dispersed over the land. A few instants afterwards the sky was as serene as on the finest days.

"The effects of this tornado were not felt beyond a strip about 160 yards in width; its course, from beginning to end, was about 4 kilometres (2½ miles) long. All the trees struck presented the same characteristics: all their sap was vaporised; the wood alone remained, and had lost nearly all cohesion; it was dried as if you had held it for forty-eight hours in an oven heated to 150°; there remained no vestige of a damp substance. This immense quantity of vapour instantaneously formed could not escape without breaking the tree, opening it in every place; and as woody fibres are less coherent longitudinally than horizontally, these trees were all split into laths along certain portions of their trunks.

"Fifteen hundred tree-roots had evidently served as conductors to these incessant electric flashes. The tree dried, and split by the intense heat, had instantly become a bad conductor, could no longer serve as an outlet for the discharge, and as it had lost its cohesion, it was broken to pieces instead of being uprooted whole."

Various theories have been proposed to explain the cyclonic phenomena, waterspouts and tornadoes. Some suppose them due to the intervention of purely mechanical causes, and liken them to the vortices that are formed in running water when there are obstacles in the water or on its surface; or they liken them to that which is observed when two currents of air, two winds in different directions,

meet and drag with them light objects or dust. But these theories, which have had illustrious advocates in Franklin and in Monge, are at least imperfect. We have seen observers agree in recognising that it is oftenest in calm weather that waterspouts on the surface of the sea take place. It may be noted that at the end of the description taken from Peltier of the tornado of Châtenay, this celebrated meteorologist attributes to electricity the principal effects that were observed.

According to him, if a storm-cloud approaching the earth is sufficiently dense and thick, the lower masses undergo the electric attraction of the earth, and elongate themselves towards it; light and movable objects are attracted towards the cone of the cloud, then having received some of its electricity they are repelled. Such is the cause of the cloud of dust that you see accompany tornadoes.

The movements of attraction and repulsion, and the electric discharges which take place in the midst of the whirlwind and along all its path between the earth and the cloud, suffice to explain its destructive effects. We have seen also that the electric nature of the cyclone serves to render an account of certain phenomena inexplicable without it.

But it is possible, and even probable, that the phenomena which have received the various names of cyclones, tornadoes, whirlwinds, and waterspout, have not always the same origin.

Of 137 cyclones of which Peltier has given an account in his treatise, thirty-three were produced in calm weather; thirty-seven were characterised by whirling movements; twenty-five did not present that kind of movement. According to Pouillet, a tornado which, in 1845, ravaged the environs of Rouen, and particularly the valley between Malaunay and Monville, presented none of the electric characteristics.

But this opinion has been contested, and other philosophers have remarked that this tornado was influenced by the factories full of machinery and masses of metal, which offered to the electricity a more easy and rapid passage to earth.

[The editor of this work will only add briefly his opinion that the electric phenomena so frequently accompanying cyclonic movements of the air are essentially secondary in their character. There seems to be no doubt that both tornadoes and waterspouts have their origin

in the heating by the sun of the layers of air near the surface of land or sea, such heating, when the whole air is still producing a state of unstable equilibrium, which, when once disturbed, precipitates a sudden violent movement. From all sides the heated stratum rushes toward the place where an uprush of heated air has begun, and the inrush is accompanied by a whirling movement. The electric phenomena, due to the difference in the electric states of the air close to the soil and of the descending cooler air, are, according to this view, in no way the cause of the cyclonic movement, though, as shown above, they may add to its destructive power.—ED.]

CHAPTER XIII.

ATMOSPHERIC ELECTRICITY

§ 1.—*Atmospheric Electricity: Instruments and Methods of Observation.*

IF the clouds during stormy weather are charged with electricity, and if there comes a moment when their charges are such that the electric equilibrium is disturbed, and that lightning, thunder, and all the phenomena that we have described occur; if, in other language, there comes about a meteorological crisis which serves to re-establish electric equilibrium, one may well ask what is the cause of this extraordinary production of electricity, and whether, in the ordinary state of the atmosphere, otherwise than in storm, one may not find some trace and origin of it.

It was a physicist of the last century, Le Monnier, who first detected atmospheric electricity. Le Monnier's experiments were made in a garden at St. Germain in 1775. They lasted during a drought of almost six weeks, from the middle of September to the end of October. Scarcely during this time was the serenity of the sky disturbed by any clouds. Even under a clear sky he found signs of electricity. To show this, he made use of an insulated metal rod, placed upright: it was like the apparatus employed by Dalibard to discover the electricity of storm clouds. He succeeded in drawing some sparks at a time when there was no appearance of clouds in the atmosphere. When the sky was covered with clouds moving slowly in damp but not rainy weather, and when the wind blew violently, he obtained no indication of electricity in the air.

Since the time of Le Monnier, innumerable observations have been made on this interesting branch of meteorology. Before dealing

with the principal results of these researches, we shall pass in review the methods and the apparatus employed to prove the presence of atmospheric electricity, to detect the nature of it, and to measure as nearly as possible its intensity.

For the insulated iron stems of Dalibard and Le Monnier were very soon substituted the kites of which Franklin had so happily made use for the study of the electricity of thunder storms. But these did not do for permanent observations. Father Beccaria studied atmospheric electricity for fifteen consecutive years by the following method:—

His observatory, situated on the top of Mount Garzegna, near Mondovi, looked over the plains of Piedmont; his apparatus was a long metal wire, which extended from a cherry tree to a stick fixed on a chimney; the ends of the wire were insulated by means of glass tubes covered with sealing-wax; a conducting rod attached to the wire penetrated into his room through a square of glass. He made all his observations on electricity collected in this way. Afterwards, he used an insulated cord, about 500 yards long, that he had stretched across the River Po.

An English physicist, Read, designed the following apparatus. A pole of fir-wood, 20 feet long, fixed and insulated at its lower part by glass supports covered with sealing-wax, was erected in the highest room in the house. Its upper end went through the ceiling and the roof without touching them, and a sort of tin cap, fixed on the top of the pole, shaded the lower part from the rain. An iron rod surmounted the fir pole, and was connected with the interior of the room by iron wires descending along the mast; these wires were brought into the room and connected to an insulated ball, the electric state of which Read studied. He had taken care to place near the ball a conductor communicating with the earth, and that was put in contact with it whenever an electric chime of bells (p. 224) indicated that the electric potential was becoming too great.

The apparatus which Saussure adopted was merely a pith ball electrometer, surmounted by a cap, and a more or less elongated metal point. The object of the cap was to preserve from rain the layer of sealing-wax with which the bell of the electrometer was covered. Instead of pith balls he employed straws, or strips of gold leaf, the divergence of which is more or less marked according as

the potential of the electric charge is greater or less. A graduated scale marked on the glass case is used to read the angle of deviation of the gold leaves, and so to indicate the potential of the charge of electricity observed. Volta extended the efficiency of the rod by placing a piece of lighted tinder at the extremity of its point. The smoke being a conductor, the column so formed collected [1] the electricity of the air at a greater height. For the same purpose a very simple artifice has been employed, which consists of attaching by a conducting wire of great length a metal ball, which is thrown with great force vertically; the wire is attached to a ring which slides along the stem

FIG. 332.—Saussure's gold-leaf electrometer for the study of atmospheric electricity.

of the electrometer. When the ball has arrived at a great height the extended wire parts separate from the stem, and leave it electrified. Becquerel and Breschet made some observations on the Great St. Bernard on atmospheric electricity, by shooting from a bow an arrow connected in the same way to the stem of the electrometer, which in this case should not be terminated in a point, for then the apparatus would not keep its charge, nor enable the experimenter to determine its nature. The electric potential of

[1] [The action of the tinder is, strictly, to equalize the potentials between the tip of the rod and the air immediately around it.—ED.]

the atmosphere is indicated by the divergence of the straws at the moment when the ring quits the stem; and the indication refers to that layer of air to which at that moment the projectile has penetrated.

Peltier, to whom we owe some protracted researches on atmospheric electricity, employed an electrometer (Fig. 333), the exterior stem of which was surmounted by a cap and a hollow globe of copper. Inside the glass case the stem was terminated by a vertical ring. This bore a pivot, on which was suspended a bent copper

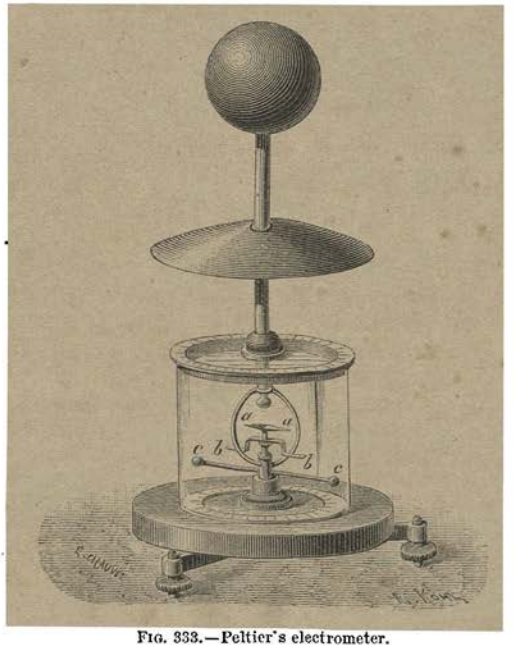

FIG. 333.—Peltier's electrometer.

needle, *b b*, which rested, as well as the small magnetic needle, *a a*, which was affixed to it, in the same vertical plane, in constant communication with the stem and the exterior conductor. Another longer and stronger needle, *c c*, is fixed below the first on the same support; this support, fixed in a glass tube filled with shellac, is also insulated. To make an observation you begin by placing the electrometer in such a position that the large needle shall be in the same vertical plane as the two others, that is to say, in the magnetic meridian. This being done, the globe of the electrometer is charged

inductively from the electricity of the air by being touched while under influence. This leaves the globe charged with a charge of opposite sign, the amount of which is afterwards read off.

Peltier's electrometer was long considered as one of the best adapted to the study of atmospheric electricity.

In England we employ by preference a modified Thomson's quadrant electrometer. We have already described this apparatus (p. 255), and we must refer the reader to the chapter which contains

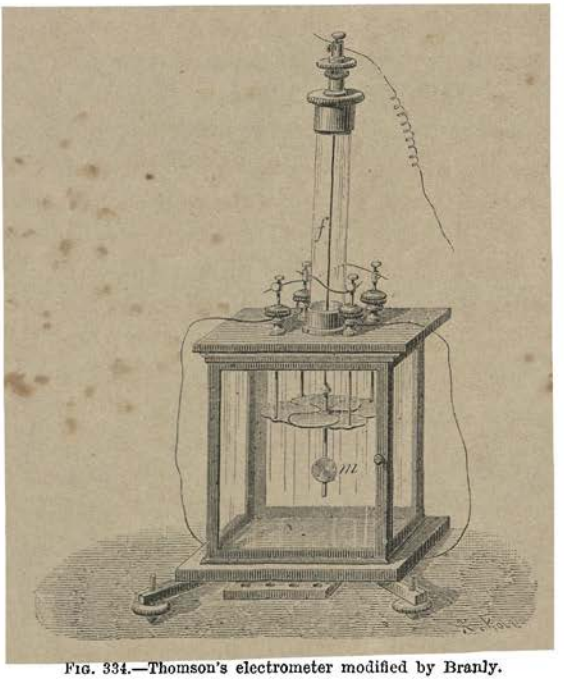

FIG. 334.—Thomson's electrometer modified by Branly.

this description and explains the principle of the instrument. Figure 334 represents a modified design by Branly, which is employed at the Meteorological Observatory of Montsouris. You see, in the interior of a square case, the four quadrants, between which is suspended the aluminium needle made in form of a lemniscate. Two of the quadrants are connected together, and are also joined to one of the poles of a battery of fifty very small cells, that you see under the case of the electrometer; the two other quadrants communicate

with the other pole. The upper end of the suspension thread is in communication with the collector of the atmospheric electricity.

The collector is of a particular form. It is situated outside the observatory, and at the distance of twelve yards from the electrometer. It is a cylindrical copper vessel nearly eight inches in diameter and a foot in height, and furnished with a side tube about one yard in length, for the outflow of water. This vessel is supported on three glass feet, on the top of a hollow cast iron column nearly six feet in height. A copper cap shelters the glass support. A copper wire, covered with a double layer of gutta-percha enclosed in a leaden casing, descends from the reservoir through the hollow pillar and communicates by a subterranean pipe with the electrometer. The water as it drops from the side tube of the reservoir through a fine orifice rapidly brings the metal vessel and all connected with it into an equality of potential with the air in the immediate neighbourhood of the orifice. The vessel is filled afresh at every experiment.

We will next see what are the results arrived at by the physicists and meteorologists who have employed these various methods of observation.

§ 2.—*Electricity of the Atmosphere.*

The electricity of the air, under a clear sky, is always positive, the earth being relatively negative, as may be especially observed at all salient points. Between the high layers of air and the earth's surface there exists a neutral layer, the thickness of which may vary from one to many metres. But the instruments give little or no sign of electrification unless they are placed in very open positions, where there is no enclosure of trees or houses or any terrestrial object. Thus, in the valleys, under the trees, in the streets of the towns, there is generally no trace of electricity; the contrary is observed in the open country or on the plains.

The potential of electricity in the air increases with the altitude. The observations of Saussure, Ermann, Becquerel, Breschet, and Peltier all confirm this result. De Saussure made observations with his electrometer while ascending the sides of mountains. We noted how Becquerel, on the plateaux of the Saint Bernard, shot an arrow

armed with a metal point, and connected to the stem of the electroscope by a ring and a silk thread covered with tinsel. Peltier made use of kites.

The law according to which the electricity of the air varies with the height is not known: it is only for small heights that Quetelet found at Brussels the change of potential proportional to the height.

The positive potential of atmospheric electricity has been verified at great heights during balloon ascents. When Biot and Gay-Lussac rose, in 1804, to a vertical height of 7,000 metres, they suspended underneath the car of the balloon a copper ball, supported by a metal wire 50 metres in length. The upper end of the wire being put in contact with the electrometer, this latter gave evident signs of electricity, which increased in intensity with the height. As for the electricity of the wire, it was always negative; but as the ball was let down into the air below it follows that the upper layers possessed in reality an excess of electric potential.

Biot and Gay-Lussac made observations during fine weather. What we have said of the positive electricity of the atmosphere is only true under this condition. When, on the other hand, the sky is covered with clouds, the electric state is very variable; the signs of electrification indicate the variations, not only in the potential, but also in the nature of the electrification of the air.

It has also been recognised that, at the same height and the same station near the ground, the electric potential varies with the hour of the day. According to the observations of De Saussure and of Schübler, it attains a first maximum towards six or seven o'clock in the morning in summer, towards eight or nine o'clock in spring or autumn, and between ten o'clock and midday in winter. Arrived at its maximum, the potential diminishes at first rapidly, then more slowly, and attains its first minimum between four and six o'clock in the evening in summer, towards three o'clock in winter. Then, when the sun begins to set, atmospheric electricity begins again to increase, continues to do so very sensibly when the sun passes under the horizon, still continues to increase during twilight, and reaches a second maximum an hour and a half or two hours after the setting of the sun. This maximum is about equal to that of the morning, but it does not last so long, and a slow diminution succeeds till just before sunrise.

So much for the diurnal period. But the atmospheric electricity observable in fine weather undergoes also annual variations. The difference of potential is generally more marked in winter than in summer. What are the causes of these oscillations? Are they connected with other elements or agencies of the atmosphere, with its hygrometric state, or with its temperature? What is the origin of the positive electrification of the air? and how, during stormy weather, do the clouds charge themselves with a negative electrification? Again, is the negative charge of the earth's surface due to induction taking place in presence of the positive charge of the upper air? or, as others think, is it something peculiar to the earth's solid crust? and if so, what is the origin of it? On all these questions science is far yet from having said its last word; continuous observations in different places, at different heights, are as yet too few to permit of a theory being formed that is free from all objections.

As far as concerns the diurnal and annual variations, the following is the explanation most generally admitted:—

The effects observed in the electrometers proceed from the exchange which is continually being effected between the ground and the upper strata of air. These effects will be the more marked the more easy the passage which the interposed medium, that is, the intermediate layer of air, permits to the flow of electricity from the positive charge above to satisfy the negative state of the earth below. Now, both dry air and unsaturated water-vapour are bad conductors in themselves, whilst, on the other hand, particles of dust and small spherules of condensed moisture, such as exist in mist and cloud, are good conductors; hence it is natural that the maxima and minima of the electric states of the air should correspond with the states of moisture in the different layers of air.

This is apparently the reason why a first maximum follows the rising sun by a few hours: the vapours at the moment of rising are condensed in the layers of mist nearest to the earth; electric communication is interrupted between these layers and the upper ones. When, by the effect of radiation, the mists are a little raised, they re-establish the communication, and the electric potential is not long in attaining its maximum; it diminishes afterwards by the fact of the increase of the heat of the air, which dries under the influence of the solar rays, and arrives at its afternoon minimum. When the sun sets,

the cooling that follows determines the condensation of the vapours in the whole thickness of the atmospheric layer; the electric exchange begins, and the indications of the electrometer become more marked, to diminish little by little during the night.

It has been remarked, not without reason, that the signs of electrification given by the apparatus, depending at once on the quantities of electricity accumulated in the atmosphere and the relative conducting power of the intermediate layers, cannot be the measure of these quantities. During winter, the conductivity being higher than during the summer, the electrometer indicates only that the current which is established between the high regions and the soil is stronger; one might then conclude that these regions possess less electricity than in summer, when the insulating power of the air is more considerable. The greater frequency of thunderstorms during the warm season is thus accounted for.

The question of the origin of atmospheric electricity is more debatable. The general well-established fact is this: The atmosphere possesses a positive electric potential which increases with the height. The earth, on the contrary, has a relatively negative potential. Whence comes the positive state of the high regions? If this origin were definitely ascertained, it is clear that the negative charge of the earth beneath would be explained by an effect of influence exercised across the intervening layers of the atmosphere.

The movement of the masses of air and their friction one against the other have been suggested as a cause, as indeed was natural, since friction was at first the only known cause of the production of electrification. Then for this explanation was substituted that of electricity developed by two operations, which act almost continuously on the surface of our globe—evaporation and vegetation. Volta was the first to show that evaporation is a source of electricity; De Saussure, Lavoisier, and Laplace confirmed the existence of the phenomenon; lastly, Pouillet studied it and determined the conditions. He saw that if the water was pure the vapour rose in a neutral state, but if the water contained salts in solution, its vapour was charged with electricity; the electrification is positive when the water is saline. The immense amount of evaporation continually going on at the surface of the sea is then a perpetual cause of the production of

electrification. The water also of springs and streams always contains salts of lime and other matters. Here then is a first source which will suffice to give an explanation of the positive state of the high regions of the air. It is the same with the act of vegetation, which consists of chemical actions producing electrification; carbonic acid proceeding from combustions of all kinds carries into the air a positive electrification, whilst the earth is left negatively electrified.

It is true that a grave objection has been made to this theory, which is, that evaporation and vegetation are more active in summer, whilst it is in winter that atmospheric electrometers mark the most pronounced electrification. But, as we have before seen, this does not prove that the electricity of the upper layers is not more abundant in summer; the apparent contradiction arises from the fact that the insulating power of the air is then greater, and the electric exchange between the earth and the air is less. Matteucci's experiments appear to have confirmed Pouillet's views.

Nevertheless, Becquerel, without rejecting this explanation of the positive electrification of the air, considers it as insufficient. In short, he does not admit that all the physical, chemical, and physiological causes which disengage charges of electricity from the surface of the earth can furnish the great quantities of electricity spread over the whole upper atmosphere, and which must be admitted to exist if one would explain the phenomena of polar auroras.

"If it were so," he says, "why does the positive potential go on increasing, when the contrary should take place, in going further from the source of electrification." This philosopher has then sought for another cause, and he thinks he has found it in the phenomena which pass on the surface of the sun. The vast spouts of glowing hydrogen gas which manifest themselves under the form of rose-coloured protuberances (seen during solar eclipses), and which astronomers now observe by the spectroscope to be continually going on, give place to a production of positive charges of electricity which spread into the interplanetary spaces by the intermediation of a ponderable cosmic medium of excessive rarity. "This electricity comes into the atmosphere of the earth, then into the ground, diminishing its intensity because of the resistance that it meets

in traversing the layers of atmosphere as they become more and more dense."[1]

We ought further to mention Peltier's theory, which, however, is incompatible with the existence of positive charges in the atmosphere in calm weather in spite of the indications of the electrometers which prove them to be there. According to him the phenomena observed are due to the influence of the negative electric charge of the soil. But then it remains to find the origin of this negative charge, and the difficulty is only postponed.

§ 3.—*Electric Countries.*

Arago, in his *Notice sur le Tonnerre,* devotes a certain number of paragraphs to solving the following questions :—

"Are there places where it never thunders?"

"Which are the places where it thunders most?"

"Does it thunder as much in the open sea as in the middle of the continents?"

"Do local circumstances influence the frequency of this phenomenon?"

"Is there as much thunder now as in past ages?"

"What is now the geographical distribution of storms as to their frequency?"

The discussion of the facts of observation which he had at that time in his possession permitted him to give an answer to some of these questions.

It seems to be proved that it is in the tropical zones that thunder is the most often heard, or that electric storms are the most frequent. In proportion as you approach high latitudes the phenomenon becomes more rare. It seems to be unknown in Spitzbergen, and in

[1] [This theory is now obviously untenable, for we know that in such excessively rare vacua as exist in the interplanetary space electricity refuses to flow. Moreover it is also known that the motion of electricity, whether flowing in a current or being transferred bodily as a charge, is always subject to the law of continuity and takes place in a circuit. Becquerel's theory does not provide the necessary return-half of the circuit from the interior of the earth to the interior of the sun.—ED.]

general beyond the 75th degree of latitude; in Iceland it scarcely ever thunders.

Local circumstances have evidently a marked influence, since in Lower Peru, at Lima, thunder is unknown. It is more frequent on continents and islands than on the sea, and becomes more rare as you remove from the coasts. Historic facts mentioned in ancient authors appear to "give probability to the idea that since very ancient times storms have diminished in intensity."

Recent researches, due to M. J. Fournet, show that certain regions are more frequently than others the seat of extraordinary electric phenomena, and thus the influence of local circumstances is not manifested by the absence or frequency of thunder-storms alone. To characterize this influence, Fournet gave the name of *Electric countries* to those regions most favoured with these singular phenomena.

It is principally on the continent of America that they have been verified. We will give some details on this subject.

Volney, in relating a voyage that he made to the United States in 1797, remarked the intensity and abundance of electricity in this country, even without storms, and he attributed it to the dryness of the air and the rapidity with which evaporation took place. A living *savant*, Professor Loomis, thus describes the effects which the presence of an excessive quantity of electricity in the air occasioned at New York: "In winter people's hair is often electrified, and especially when it is combed with a fine comb. It often rises up, and the more you try to smooth the hair the more it refuses to keep in its place. The hairs are attracted to the fingers placed near them, and to remedy this inconvenience they must be moistened.

"In this same season all parts of woollen clothing, socks particularly, attract light bits and dust which float in the air; these particles fix themselves chiefly near the feet, and the brush only makes them more adherent. A damp sponge is always the remedy in such a case.

"During the night thick carpets of heated rooms make little crackling noises; they shine when you walk upon them, and if you pass rapidly over them two or three times a spark several centimetres long is given out, so that one feels a sharp prickling. A metal object, such for example as the handle of a door, sends a spark to the hand that approaches it, and sometimes these sparks frighten children.

You can even sometimes light a gas jet with your finger after having shuffled along on the insulating carpet."

On the plains of the Andes the extreme dryness gives place to similar phenomena. It is the same with the deserts of South Africa. According to Livingstone, when the wind blows hot from the north, the electric state is such that the feathers of the ostriches become charged and give strong shocks; merely rubbing one's clothes makes them give out brushes of light. On the elevated plateaux of Mexico, according to M. H. de Saussure, the dryness becomes excessive at the end of winter, and the mere contact of things gives rise to electric sparks of remarkable brilliancy. Craveri, a physician of Mexico, has described the phenomena observed by him in an ascent made in May, 1845, up the Nevado de Toluca: "The electric sensations which he and the guides experienced," says Fournet, "at their extremities, at the tips of their fingers, on their noses and their ears, were immediately followed by a dull noise; though thunder had not yet begun. The long hair of the Indians stood up stiff, giving to these men's heads an enormous size, so that the sight of them greatly increased their superstitious terror. At last the noise became more intense, appearing to be all over the mountain, and resembled the rattling which pebbles would produce if alternately driven up and down by electricity; it was probably due to the crackling of myriads of sparks issuing from the pebbly ground."

Fournet cites analogous facts reported by various explorers of the mountains of the Jura and the Alps. We will finish by the curious recital of the phenomena observed in 1865 by the same De Saussure whose observations on the Mexican plains we have just mentioned. It was during an ascension of Piz Surley, a granite mountain of the Grisons: "Towards one o'clock in the afternoon," he says, "we were attacked by a shower of fine sleet, at the same time that similar showers enveloped the rocky mountain tops, such as the Piz Ot, Piz Jutier, Piz Languard, and the snowy tops of the Bernina, whilst a very heavy rain fell in the valley of St. Moritz.

"The cold increased, and at half-past one, having arrived at the top of Piz Surley, the fall of sleet becoming more abundant, we decided to have our meal near a pyramid of dry stones which crowned the summit. Resting my stick against this pile I felt in my back and my left shoulder a sharp pain such as a

PLATE IX.—THE JUNGFRAU.

View from the ruins of the castle of Unspunnen.

pin would produce if slowly pushed into the flesh; and on putting out my hand without finding anything a similar prick made itself felt in my right shoulder. Imagining that my overcoat contained pins, I then threw it off; but, far from finding myself relieved, the pain increased and extended all over the back, from one shoulder to the other, and the pain was accompanied by ticklings and painful shootings like those that would have been produced by a wasp or any other insect in my clothes covering me with stings.

"Quickly taking off my second coat I could discover nothing which could wound my flesh, whilst the pain now felt like a burn. My instant thought was that my woollen shirt had taken fire; and I was going to undress completely when our attention was attracted by a noise which recalled the buzzing of humble-bees. It was our sticks that were singing loudly, producing a noise like of a kettle when the water is on the point of boiling; all this lasted about four minutes.

"From that moment I was aware that my painful sensations proceeded from some very intense electric discharge that was taking place at the summit of the mountain. Some experiments improvised on our sticks gave no appearance of sparks, nor of any light appreciable by day, but they vibrated in the hand so much that they gave an intense sound. If they were turned vertically, the point either up or down, or placed horizontally, the vibrations remained the same, but the ground was inert. Then the sky became grey all over, though unequally filled with clouds.

"A few minutes after I felt my hair and my beard standing up, producing a sensation on me like that which results from a razor passed dry over stiff hairs. A young man who accompanied me said that he felt every hair in his moustache, and that from the tips of his ears there seemed to start very strong currents. On lifting up my hand I saw currents not less pronounced escaping from my fingers. In short, very strong electric discharges were flowing from the sticks and coats, from the hair, the beards, and all the salient parts of our bodies. A thunder-clap at a distance towards the east warned us that it was time to quit the top, and we descended rapidly about a hundred yards. Our sticks vibrated less and less as we went on, and we stopped when the sound that they gave had become so feeble that we could only hear it by putting them to our ears. The pain in the back had ceased from the first steps downwards, but I still retained

a vague impression of it. Ten minutes after the first clap of thunder a second was heard at a great distance, and they were the only ones. No lightning was seen, and half an hour after our departure from the top the sleet ceased and the clouds dispersed. At half-past two we reached again the summit of Piz Surley, to find the sun shining there. But, the same day, a violent storm burst over the Bernese Alps, when an English lady was struck.

"The electric phenomenon that we have described, and that may be called 'the song of the sticks' or the 'humming of the rocks,' is not rare in high mountains, without however being frequent. Among the guides whom I have interrogated on this subject, some had never observed it, others had only heard it once or twice in their lives. It must be observed that it happens precisely on the days when the threatening sky warns travellers from mounting to elevated points."

Like phenomena had been observed two years before by Watson and a party of tourists and guides who visited the summit of the Jungfrau. Instead of a fall of sleet there was an abundant downpour of snow, which was accompanied by singular manifestations of an electric nature. To the whistling of sticks, hatchets, and other salient objects there was added a noise proceeding from the flakes of snow, like, says Mr. Watson, to the noise of a heavy fall of hail.

It would then appear as if certain regions were specially endowed with the power of producing unusually powerful electric phenomena; and that amongst these we may reckon those parts of the earth which by their altitude, or their salient and pointed form, are rendered particularly able to promote the flow of electric discharges from the surface of the earth. In the first case, the phenomena are explained by the persistence of certain winds, by the abundant evaporation which they excite, by the consequent dryness of the air which is known to be a condition of the manifestation of signs of electrification. But although we can thus give in general terms a reason for the facts observed, still we know little of the complex circumstances of their production, or of their connexion with other meteorological phenomena.

SECOND PART.

APPLICATIONS OF PHENOMENA AND LAWS OF MAGNETISM AND ELECTRICITY.

CHAPTER I.

THE MARINER'S COMPASS.

§ 1.—*Declination Compass: its Uses in Navigation.*

LONG before the laws of magnetic phenomena were known the mariner's compass was used in ocean navigation when the sky, covered by clouds or fog, gave no astronomical indication which mariners might follow. It is one of the most striking examples of an application of the phenomena of physics long before the discovery of its laws or theory. "A thousand years and more before our era," says Humboldt, in his well-known work, *Cosmos*, "in the very obscure epoch of Codrus, and of the return of the Heraclidæ into Peloponnesus, the Chinese already possessed *magnetic balances*, one arm of which bore a human figure which always indicated the south; and they used this compass to direct themselves across the immense steppes of Tartary. Already in the third century of our era, that is to say, seven hundred years at least before the introduction of the compass into the European seas, Chinese junks navigated the Indian Ocean according to the magnetic indication of the south."

We mentioned in the earlier part of this work the Chinese "cars indicating the south," of which Humboldt spoke: in their most early form they consisted of a little statuette turning on a vertical pivot one of the arms was extended towards the south, because it inclosed a magnetic needle, the south-pointing pole of which lay towards the hand, whilst the north-pointing pole was set towards the shoulder.

Later, in the second century, the Chinese compass was arranged in another way, which was transmitted by Arabs to the European navigators about the time of the first Crusades. This was a lode-

stone, or in some cases a magnetic needle, placed on a float in water. It was only towards the first half of the fourteenth century[1] that this instrument, so useful to navigation, received a new improvement, and that the magnetic needle of the compass was poised on a pivot. This improvement is claimed for a Neapolitan, Flavio de Gioia, to whom the invention of the compass was at first attributed.

The magnetic compass furnishes the navigator with one of the elements necessary for the direction of their vessels across the sea; for it tells them the angle which their vessel makes with the magnetic meridian of the place where they are. In navigation, the other element, distance, is reckoned either by astronomical means by comparing the time of apparent noon with the time kept by a good

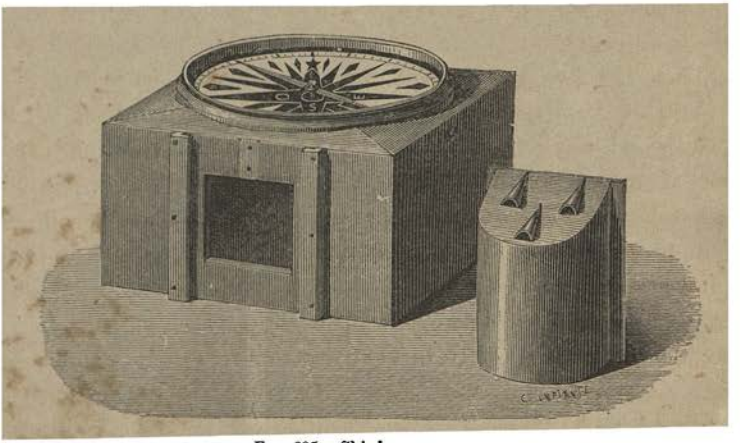

FIG. 335.—Ship's compass.

chronometer, or it is determined from observations made on the speed of the ship by means of casting the log.

The mariner's compass is permanently fixed in a sort of box or

[1] The compass with a floating lodestone was described in the verses of an old French poet of the twelfth century, Guyot de Provins, in the following verses, in which it is called a *marinette*:

"Icelle estoile ne se muet,
Un art font qui mentir ne puet;
Par vertu de la marinette,
Une pierre laide noirette,
Où li fers volontiers se joint," &c.

According to Littré, its present French name was taken from the Italian *bossolo*, little box.

closet, called the binnacle, in some convenient place for steering. The binnacle is often divided into three compartments: one in the middle containing a lamp used for observations in the night, the two others containing each a compass, so as to allow the readings of the one to be confirmed by a glance at the other. More frequently there is a single compass lit by a lamp at the side.

In the mariner's compass the magnetic needle rests on a pivot, in the centre of a copper basin or case; it carries upon it a light disk or "*card*," on which is traced the various "*points of the compass.*"

The copper cup, loaded with a suitable mass of metal, is itself supported in the binnacle by the help of a particular kind of suspension,[1] known as *Cardan's suspension*, or "gimbals," so as to keep the compass level whatever may be the movements of the ship. An arrow-head engraved at the rim of the compass-box marks the point exactly in the fore and aft line, and is sometimes called the head of the compass.

If the edge of the compass card is divided into degrees you may at any instant read off on the edge of the card the angle which the ship's head makes with the magnetic needle. By adding to this angle the local magnetic declination, or by subtracting it, as the case may be, you will find as a result the angle which the ship makes with the geographical meridian.

The employment of the mariner's compass for maritime navigation presupposes, as is evident, a knowledge of the value of the magnetic declination in the places where the mariner makes his observation. But that it may be reliable no causes of perturbation must exist near him, such as would cause an error; for error would be all the more serious from being unsuspected. Now, such a cause of error does exist, in consequence of the action on the magnetic needle of the

[1] This kind of suspension is used whenever it is desired to keep an object in its position relatively to the plane of the horizon, irrespective of the movements of its support. This is done in pivoting the object on a pair of trunions horizontally; the trunions resting in bearings in the edge of a substantial ring which itself is supported by a pair of horizontal trunions lying at right angles to the inner pair. Weight alone always brings the suspended object into its proper position, thanks to the two simultaneous rotations around the two horizontal axes. In the case of the mariner's compass, the two trunions on the compass-box itself usually have a direction athwart the ship; the two outer trunions on the ring lie fore and aft.

masses of iron which the ship contains. The temporary magnetisation due to the action of the earth itself on these masses, is specially to be feared, because it varies with the position and direction of the ship.

The influence of the iron of vessels on the direction of the needle of the compass has for long been known. Many able navigators, Parry, Ross, Sabine and Duperrey have tried to remedy it; at first by

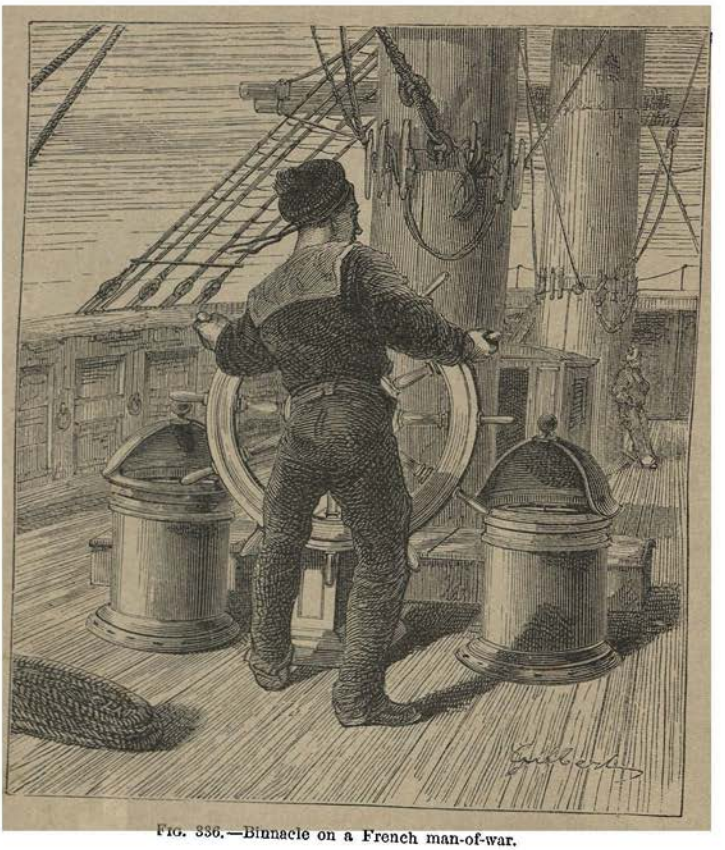

FIG. 336.—Binnacle on a French man-of-war.

having no piece of iron near the stern of the vessel where the compass is; then by studying beforehand the deviation produced, and compensating for it by the action of other suitably placed masses of iron. The *compensating magnets* or correction plates proposed by Barlow necessitate first a study of the deviations which the compass undergoes under the action of the iron of the vessel, when lying in different

positions, comparing the indications of the compass with the known angle of the ship, then finding out where to place the compensator to produce equal and opposite deviations.

But there is always some difficulty arising from the magnetic state of the masses of iron on board, not being always the same; nor indeed is that of the compensating pieces. They both vary with temperatures and with changes of latitude. Besides, now that the number of iron vessels and of ironclads is so great, such causes of error become more marked, and it seems certain that the error of the compass on vessels thus constructed has been the principal cause of many disasters. In driving the rivets of an iron vessel powerful magnetism is developed, the direction of the magnetism depending on the position of the ship in construction. An iron ship built with her head to the north has her head always a north pole and her stern a south pole. This magnetism acts on the compass preventing it from pointing properly, and this action produces an error that must be calculated and allowed for in the reckoning. Putting up another compass in another part of the vessel permits of the necessary corrections being made. Another means employed is to place at a convenient position a bar or bars of soft iron as compensators.

Unfortunately, as we have said, it happens that, during the voyage, the usual magnetism of the vessel changes in direction and intensity, and then the risk is all the greater. On board most of the ships of the British Navy, a second compass is usually carried aloft near the mast-head, where it is less subject to such errors, and with this compass the other compass in the binnacle is from time to time compared.

Whether you employ the method which consists in determining for each vessel the law of perturbations that its compass undergoes, and to deduce from it by calculation a table of corrections to apply to each of its indications, or that you neutralise the effects of deviation by the employment of compensators, still it is certain that both these methods may be and often are in fault. Experience proves that during a voyage changes are produced in the polarity of iron vessels, and in the direction of its magnetisation relatively to the meridian, from which necessarily there result grave errors. "The error of the compass by the action of iron," says Evan Hopkins in a note on this subject read at the Academy of Sciences, "threatens to be fatal to the

life and property of many people." The number of ships constructed of iron, very much exceeds that of wooden ships, particularly those destined for the transport of passengers. Numerous accidents have taken place in the Channel and other places, and many ships, during late years, have been wrecked in consequence of the great errors of their compasses. Though these facts are now well established, it is supposed that they are incurable evils inseparable from iron vessels, to which we must be resigned, since they cannot be avoided.

The same authority enumerates as follows the remedies proposed to prevent the dangers arising from the perturbations of the compass in iron vessels :—

1. To neutralise or destroy the polarity acquired by an iron vessel, during its construction, by means of a horse-shoe magnet.

2. To raise the compass to such a height that it shall be beyond the sphere of activity of the attraction exercised by the wrought iron of the ship.

3. To place a mirror near the compass so that the card can be seen like the dial of a clock, and clearly read at a distance of 20 feet from the helm.

4. To place a dummy card opposite the wheel-house to guide the man at the wheel, and thus to avoid the mistakes proceeding from verbal indications, the compass card and the dummy card being regulated to agree together.

5. To construct, and employ magnetic needles having the greatest directive force, in order to avoid instability and excessive oscillations.

6. To employ the curved needles arranged for navigation in high latitudes, where straight needles are sluggish in their movements, and consequently have an uncertain direction.

M. E. Duchemin has devised a circular compass, represented in Fig. 337, and which he claims as possessing a certain superiority over the needles of the ordinary compass. It is said to answer to the desideratum expressed in the fifth condition enumerated by Hopkins; a greater directing force, and more sure stability. It is formed of two concentric circles of steel, magnetised, and bound together by a cross-piece of aluminium.

At the points marked N.S., north and south, the magnetism is at its greatest; from these points it decreases gradually to the extremities of the perpendicular diameter *n n*, where it is *nil*, this being the

neutral line of the system of magnetised circles. It is suspended upon a pivot by an onyx cap.

Many comparative experiments were made on ships of the line in the course of the years 1874, 1875, &c., and they were favourable to the employment of Duchemin's compass. Its sensitiveness was considered superior to that of the needles of ordinary compasses, which is due no doubt to the fact that with an equal weight a circular ring is susceptible of storing up a greater quantity of magnetism than a bar.[1] It is also more stable, its oscillations are slower than that of the needle.

[In Sir William Thomson's compasses the single magnetised needle

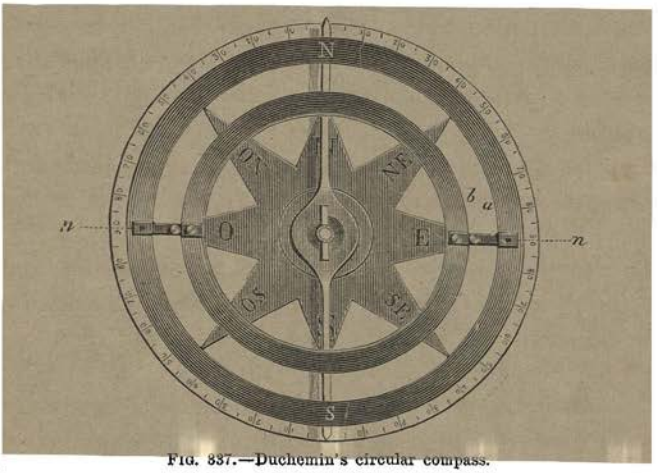

FIG. 837.—Duchemin's circular compass.

is replaced by eight short steel wires, each strongly magnetised, and suspended side by side in a system of threads attached to the compass card. This beautiful instrument has many other details of improvement, such as a transparent card of mica. It is very largely used in the Royal Navy and on most large ocean-going steamers.]

In navigation there is also a compass used which has for its object to determine precisely the magnetic declination, by an operation like that which we have already described (Book II., § 2 of Chapter IV. on magnetism). A known star is observed and its azimuth is measured,

[1 The editor dissents from this proposition: and has doubts whether the Duchemin compass is superior in any one point.—ED.]

which gives, by the aid of a calculation into which the hour of the observation enters, the direction of the meridian: and the declination is concluded from that. This compass is known to seamen under the

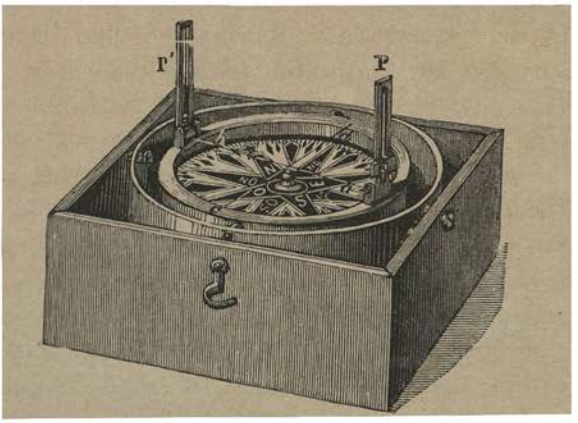

FIG. 338.—Variation compass.

name of "variation compass." It is portable, like the compass shown in Fig. 339, and only differs essentially from that instrument by having the telescope replaced by a concentric graduated circle with

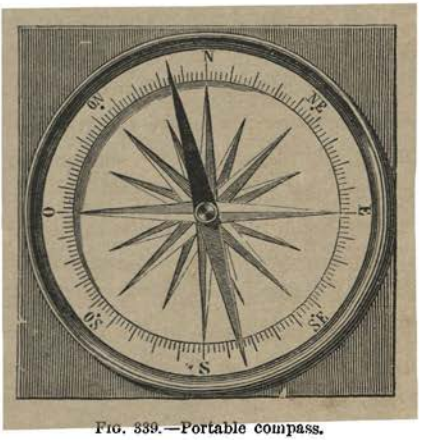

FIG. 339.—Portable compass.

two sights P P′ (Fig. 338) diametrically opposite to each other. The box in which the magnetic needle is placed with its divided limb is suspended on gimbals. Two wires crossed at right angles are stretched

across the edge of the box which contains the needle, and one of them gives the direction of the slits of the sights, and consequently that of the plane of vision. One of the sights has a mirror at 45°, where the observer sees reflected the divided edge of the card at the same time that he sees the star through the slits of the sights and through a part of the mirror from which the silvering has been removed.

Whilst an observer looks at the star, the moon, the sun, or a terrestrial object, and reads in the mirror the division which the angle of the magnetic needle makes with the vertical line drawn through the object looked at, another observer makes a second reading by the aid of the wire which is stretched at a right angle in the direction of the sights; this second reading serves to verify the first. With this instrument you can only look at objects a little raised above the horizon; at the most 15° or 20°. To obviate this a second auxiliary mirror may be employed.

§ 2.—*The Declination Compass employed in Geography and Surveying.*

Travellers in their geographical explorations of continents, and geologists who want to know the direction of the mountain chains or other variations of the land, employ the magnetic compass as well as sailors. Only as the instrument is easy to arrange in a fixed place, it does not want such a complex mode of suspension; a simple tripod is sufficient, the compass being attached by an elbow-joint, and provided with a spirit-level to ensure the horizontality of the scale. A little telescope with cross-wires eye-piece, which moves parallel to the line of sight in a vertical plane, permits you to look in the direction of the line that it is necessary to consider.

The more simple compasses have, instead of a telescope, a graduated circle with sights.

Since the angle of a line with the meridian is quickly found with this compass, when the magnetic declination of a place is known, it is clear that if you have determined in this way the azimuthal angles of a series of horizontal lines, for example, those of the sides of a polygon, you will only have to find the difference between these angles to obtain

the angles which the lines themselves make between themselves. Much more, if the only thing needed is the determination of the angles of a polygon, it can be done in the same way, without the necessity of knowing the magnetic declination. It is enough if during the operation the direction of the magnetic needle remains constant; which it does sufficiently during the ordinary time required

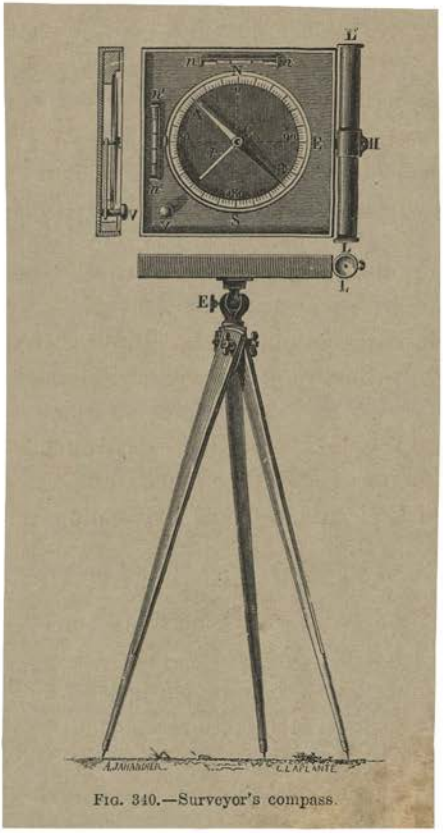

FIG. 340.—Surveyor's compass.

for topographic operations. Such is the principle which regulates the employment of the compass in surveying. But the measure of angles by this method is not exact enough when you must answer for more than a half or a quarter of a degree; the oscillation of the needle which renders the reading of the angle difficult, the diurnal variations of the declension (which sometimes are very considerable) are the principal causes of this want of precision.

Compasses have been constructed for expeditious surveying, for example, for military purposes, which do not even give the approximation we have mentioned, for a very simple reason, that, instead of the instrument being fixed, hand observation is substituted.

The following description of two or three of these apparatus, which are of great use in the special circumstances where they

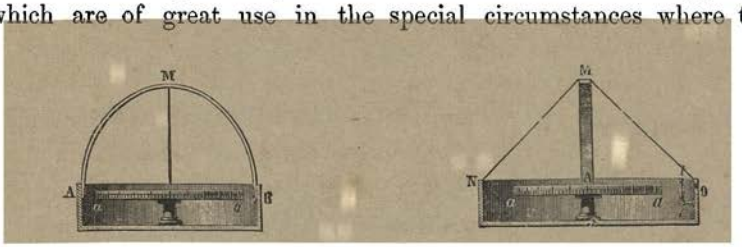

FIG. 341.—Burnier's compass; lateral section. FIG. 342.—Burnier's compass; longitudinal section.

are employed, is taken from Sonnet's *Dictionary of Applied Mathematics*:—

"Burnier's compass, contained in an elliptical box, is composed of a magnetic needle with a very thin cylindrical band, *a a a* (Figs. 341 and 342), which serves as a scale, and on which the divisions are traced vertically. The line of sight is determined by a horse hair O M N, fixed at the two ends to the two extremities of a diameter of the box, and which is stretched out by means of an elliptical arch

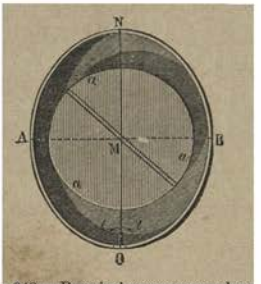

FIG. 343.—Burnier's compass; plan.

A M B, which turns round the points A and B, and can take the vertical position which, when not stretching the hair, may be folded down inside the box.

"The divisions of the vertical scale are read through a circular orifice O, made in the box in the plane of the stretched hair; this orifice is furnished with a magnifying-glass *l l*, to facilitate the

reading. At the same time that you look at a distant point making use of the hair as a sight, you read through the circular hole the number of the division of the vertical scale which appears before

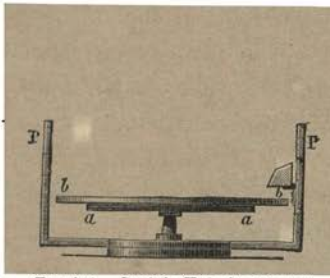

FIG. 344.—Captain Kater's compass; section.

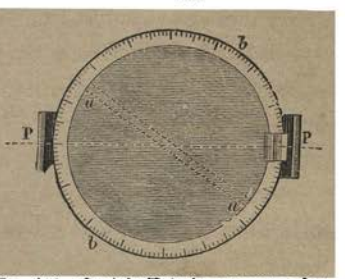

FIG. 345.—Captain Kater's compass; plan.

the eye; this is the measure of the angle which the line of sight makes with the magnetic meridian.

"In Captain Kater's compass (Figs. 344 and 345) the needle *a a*

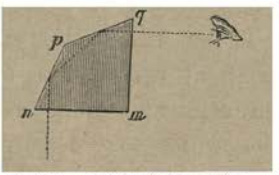

FIG. 346.—Total reflexion prism.

bears a horizontal scale *b b*; at the same time that you look at an object by means of the sights P P, the eye can perceive, by double total reflexion through a prism, *m n p q* (Fig. 346), the number

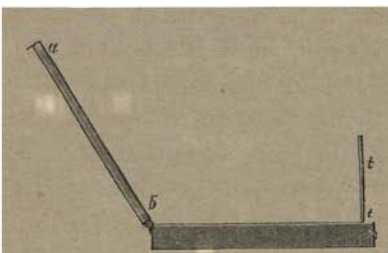

FIG. 347.—Hossard's compass; section.

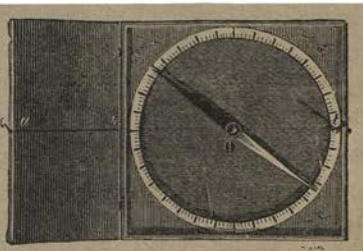

FIG. 348.—Hossard's compass.

of the division of the scale, which is presented under the prism in the vertical plane of the line of sight. Often the prism is replaced by a mirror inclined at 45°, which produces the same effect.

"In Hossard's compass (Figs. 347 and 348) the scale is fixed to the box, which has a cover opening with hinges, and the inside of which is a mirror. In the vertical plane of symmetry of this mirror there is traced a very visible line *a b*; and in the middle of the opposite edge of the box there is a vertical wire rod *t t*, which can be put down horizontally when the box is closed. To look at an object you must turn your back on it, so that its image shall be vertically cut by the rod *t t*, by the rod's image, and by the line *a b* of the mirror. The measure of the angle which the line of sight makes with the magnetic meridian is read directly on the scale at the same time as the observation is made."

These three compasses are so small that they can be held in the hand during the observation, and put in the pocket when it is finished.

§ 3.—*The Use of the Compass in Searching for Iron Mines.*

A Swedish *savant*, Thalen, has studied the influence which the proximity a sufficiently great bed of iron ore produces in the indications of the declination compass, and he has deduced as results of this study some rules which may have, in a technical point of view, a real practical importance in the art of the mining engineer.

When you observe in any place whatever a declination compass, and can, by the method of its oscillations, for example, determine the value of the horizontal component of the terrestrial magnetism in this place: this component does not in general vary sensibly over considerable extents of area. But it is otherwise if the observer is in a region where there exists beneath the ground, large or small masses of oxide or ore of iron. In this case the magnetic intensity as determined by the aid of the compass is the resultant of the combined actions of the globe on one hand, and of the perturbing masses on the other. By putting himself into different positions the observer will obtain different values for the intensity, because if the horizontal component of the magnetism of the globe remains, as we have said, sensibly the same, it is quite otherwise with the horizontal and vertical components of the forces due to neighbouring masses of ore; their polarity and their distance from the compass vary with the change of position of the

observer. The resultant of these two actions varies then in the neighbourhood of iron mines, and the study of these variations can furnish indications on the extent and depth of the layer. By taking the value of the intensity in a great many points you will find at least two points, which we may call *a* and A, where the value reaches a minimum and a maximum. By joining with lines on the map the points where the intensity has equal values intermediate between the two extreme values, you will have curves that may be called *isodynamics*, analogous to the terrestrial isodynamics (p. 83). These two curves form systems, one enveloping the minimum point of intensity *a*, the other the maximum point of intensity A, and separated by a nearly straight line where the intensity is midway between maximum and minimum. That is the neutral line.

Now Thalen has shown: (1). That the general direction of the layer of magnetic ore lies along the line joining the two points which form the centres of the two systems; (2) That the distance from the magnetic meridian of the point A to the point of intersection of the neutral line with A *a* is equal to half of the distance from the centre of the mass of ore to the surface, if this mass is situated at a great depth. Hence Thalen deduces this practical rule, that in beginning to work the mine *digging must be begun under the point* A. This rule applies still more strongly to the case where the ore is near the surface.

The laws of magnetism assign theoretical reasons for the results of Thalen's researches. But these results have also been confirmed by experimental verifications made on mines that have been actually worked; hence it is easy to conclude that the employment of the compass in seeking for mines of iron ore will be henceforth an indispensable, or at least very useful auxiliary in the mining engineer's art.

CHAPTER II.

LIGHTNING-CONDUCTORS.

§ 1.—*Principles which serve as Bases in the Construction of Lightning-Conductors.*

ARAGO, in his *Notice sur le Tonnerre*, reviews the different means to which, from ancient times down to the time of Franklin, and even to the present day, popular prejudice or scientific bias attributes the power of dissipating storms or preserving from the lightning stroke. A great number of these means have their origin in some superstitious belief, and do not deserve mention. Some are founded on hypotheses which experience has not justified, or has even contradicted.

For example, it was once thought that great fires lighted in the open air deprived the clouds, partly at least, of their fulminating properties. This was Volta's opinion, based doubtless on a fact of experiment, that flames and heated gases are good conductors of electricity. But does it happen in the case of fires lighted in the open air that the columns of heated gases rise to a sufficient height to reach the storm-clouds? It has been said that in some places peasants were in the habit of lighting, at the approach of storms, great heaps of straw, distributed here and there in the fields, and that these places had not been devastated by lightning or by hail. But, on the other hand, great fires have taken place a little before or during great storms, without the clouds, even those nearest to the place of the disaster, seeming to be at all deprived of their electricity. The efficacy of this method is at least doubtful.

Another means of dissipating clouds of all sorts, and consequently storm-clouds, has been frequently employed by sailors and by farmers.

It is that of producing detonations of artillery, firing off cannons or mortars. But the very opposite examples which Arago cites for and against this method prove that it is far from being really efficacious. It has not even ever been proved that it has had any influence whatever on the dispersion of the clouds; and it would be quite as possible from the facts known to draw the opposite conclusion.

The same may be said of the sound of bells. The custom of ringing the bells of the church during storms has no origin but that of superstition, and the most certain effect of this practice is to make the ringers run into a real danger for the sake of avoiding by the aid of imaginary help a danger that is in reality much less. Lightning strikes in preference elevated objects, particularly those which, like bell towers, are almost always surmounted by isolated pieces of metal.

Since the time of Franklin, who was, as is well known, the inventor of lightning-conductors, science can recommend no other means of preserving buildings from lightning, or their inhabitants, than this simple apparatus, which is almost always efficacious if it is constructed and fixed according to the conditions which experience and theory agree in regarding as necessary.

The lightning conductor is an application of the power which metal points possess of discharging electrified bodies placed near them, and the idea of utilizing this property, which the illustrious American discovered, was the natural result of his views as to the identity of lightning and thunder with electric phenomena. It is well known that the experiments which demonstrated this identity took place almost simultaneously in 1752 in America and France. Franklin, living at that time at Philadelphia, sent up his famous kite, armed with a point, and drew down sparks from a storm-cloud. The French experimenter, Dalibard, verified at the same time the ideas suggested by Franklin by setting up an insulated bar of iron, about 45 feet high, in the plain of Marly-la-Ville.

A little time after the first lightning-conductors were put up at Philadelphia. From America they passed into Europe, and the first that was seen in France was put up at Dijon by Guyton de Morveau.

The first authoritative report made on this interesting question dates from April 24th, 1784, and the names of Coulomb, La Place, and

that of Franklin himself are among those who drew it up. In 1799, 1807, 1823, and 1855 fresh reports were also prepared by special commissioners, and submitted to the approbation of the *Académie des Sciences.*

A still more recent report on the employment and construction of lightning conductors is due to a commission of the *Académie des Sciences,* which made its report on January 14th, 1867, at the hands of M. Pouillet. It is this report which furnishes us with the elements of our description.

First let us lay down the theory of storm-clouds and of the action of lightning-conductors on the electricity which they contain.

"(1) Storm-clouds which carry lightning are nothing else but ordinary clouds charged with a great quantity of electricity.

"The lightning which furrows the sky is an immense electric spark, the two points of departure of which are two separate clouds charged with contrary electricities.

"Thunder is the noise of the spark.

"Lightning is the spark itself; it is the recomposition of opposite electrifications.

"When one of the points of departure of the lightning is at the surface of the ground, then the thunder is said to fall, or sometimes it is said that the thunder-bolt falls, and objects on the land are said to be struck. Then all the points of the furrow of the lightning are still the places of recomposition or the neutralization of the two contrary electric charges, one of which is furnished by the cloud, the other by the earth itself.

"How is it that the earth, which is generally in a neutral state, and without apparent electricity, is thus charged with electricity, and with an electricity contrary to that of the cloud at the moment when it is struck?

"Such is the first question which we have to examine.

"(2) Before the lightning bursts forth, the storm-cloud which bears it, though it may be many miles high, acts by inductive influence to repel electricity of the same name and to attract electricity of the contrary name.[1] This influence has a tendency to

[1 The reader will not fail to note that in this report the old ideas of the two fluid theory of electricity dominate the language. The modern way of regarding the action called "influence" or "induction" is expounded on page 180 *et seq.*—ED.]

exercise itself on all bodies, but it is really efficacious only on good conductors; these are, in different degrees, metals, water, very damp ground, living bodies, vegetables, &c.

"The same conductor experiences from the cloud very different effects according to its form and dimensions, and above all to its perfect or imperfect communication with the ground.

"A tree, for example, when it is in ground only slightly damp has opposite electricity only slightly induced in it because electricity of the same name cannot be repelled far into such ground, which is a bad conductor for great electric charges.

"If the tree, on the contrary, is in very damp ground of great extent, it will be strongly charged by induction, because electricity of the same name can be spread very far in this good conductor. In short, it will be charged as much as possible, if this good conductor, towards its limits, is itself in good communication with other indefinite sheets of water.

"When we are dealing with the electricity of our machines the surface of the ground as it presents itself is what is called the 'earth,' or the 'common reservoir.' It may be thus called since its conductivity is sufficient to disperse all these small electric charges.

"When we are dealing with lightning the soil in its habitual state is no longer what may be called the common reservoir; it acts as a relatively bad conductor, and so also do the geological formations of different periods that lie below it. We must come to the first sheet of water, that is to say, the wet stratum of the wells that are never dried up (we shall call it here the subterranean nappe) to find a layer where the conductivity is sufficiently great. This, by reason of its extent, and its multiplied ramifications, cannot be insulated from the courses of neighbouring waters, and with them, with the streams and rivers, with the sea itself, it constitutes what may be called the common reservoir of sufficient capacity not to become overcharged when there is suddenly led into it the electricity that is developed by a big storm. This subterranean nappe, though in many places not well defined, may be considered as the 'common reservoir' or true 'earth' into which the lightning-conductors pour the electricity that they receive from the clouds.

"In short, whilst the storm-cloud exercises everywhere underneath it its attractive influence on the fluid of a contrary name, and

its repulsive influence on the fluid of the same name, it is particularly the subterranean nappe that receives this influence with incomparable efficacy. Then all its upper surface is charged with contrary electricity, which the cloud accumulates there by its attraction, whilst the electricity of the same name is repelled, and dispersed to a distance in the common reservoir. So, when the lightning bursts, the two points of departure of the lightning are, one on the cloud, the other on the subterranean sheet of water, which is, in a sense, the second cloud necessary for the explosion of the lightning.

"It is thus that the globe of the earth, without ceasing to be in its natural state as a whole, is sometimes electrified on some points by the presence of storm-clouds.

"Buildings, trees, living bodies struck by lightning, must only be considered as intermediate objects which it meets on its way and strikes in passing.

"It must not be hence concluded that these intermediate objects are essentially passive, and do not contribute to modify or even to determine the direction of a flash of lightning. It is certain on the contrary that they do exercise in this way an action great or small according to their extent and conductivity. For example, when a vessel is struck in the middle of the sea, it is very probable that the lightning has not taken the path that would have been geometrically the shortest to arrive at the water which it seeks, and where it would be neutralized by the contrary electricity, but it has taken the road that was electrically the shortest because of the decompositions which the cloud had before produced by influence on the masts, the rigging, and other conducting bodies of the vessel, placed more or less high, and being more or less conductors.

"This phenomenon is like that which the spark presents when drawn at a great distance from the conductors of a powerful electric machine: it can be turned from its most direct road by the presence of one or many insulating conductors placed near its path; it strikes the same mark, but it arrives there by a way that is electrically shorter, though it may be longer in appearance.

"These insulating bodies here change the direction of the spark; the intermediate objects of which we spoke just now change the direction of the lightning.

"We limit ourselves to the simple enunciation of this fundamental

principle, which we cannot here develop; it contains the explanation of all the movements, however extraordinary, of lightning strokes, and of all the destructive effects which they produce; you can never render an account of them without thoroughly recognizing the two points of departure, and between these two points the series of intermediate objects which have been struck in the path, sometimes simple, sometimes multiple, of the lightning."

Here ends the theoretical part of the report, which the members of the commission considered as the basis of the practical indications subsequently formulated for the construction and arrangement of lightning-conductors. Now we shall present these indications so far as they are essential.

§ 2.—*Description and Arrangement of Lightning-Conductors.*

A *lightning-conductor* is nothing else but a good continuous conductor, the upper end of which rises to a sufficient height to go beyond the building it is to protect, and the lower end communicating completely with the conducting subterranean nappe.

Lightning can melt or volatilize metal wire of small diameter, a quarter of an inch in diameter, for example, but there is no example of its having heated to redness good square stems of iron of two-thirds of an inch square; conductors may therefore be made of bars of iron having this dimension. [They may equally well be made of copper rod or solid copper tape of much less thickness.]

[The following description is characteristic of lightning-conductors such as are universal in France. In England a different form prevails, as will be duly noted.]

A [French] lightning conductor, or *paratonnerre*, is composed of two parts—the "stem" and the "conductor." The following is a description of each.

The iron "stem," which forms the upper end, ought to be terminated by a copper cylinder two centimetres in diameter, and from twenty to twenty-five centimetres in length, joined to the stem by a screw (Fig. 349). This cylinder is terminated by a cone at its summit. Underneath the stem is square, and increases gradually in thickness up to the point of insertion of the "conductor": there the

section measures four or five centimetres on the side. According to circumstances, the total height of the stem varies from three to five metres.

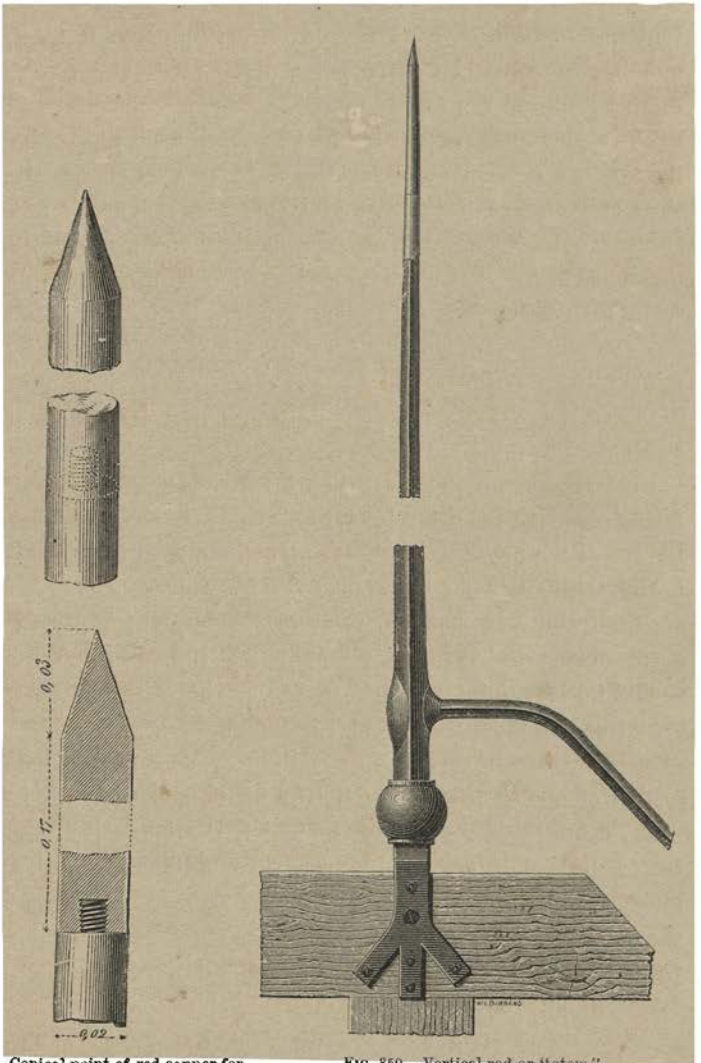

FIG. 349.—Conical point of red copper for the tip of the lightning rod.

FIG. 350.—Vertical rod or "stem" of the lightning conductor.

At one time it was the fashion to terminate the stem by a very fine sharp point of gold or platinum. It then happened that at the very first stormy weather, the electricity ran along the point under

the form of a luminous plume visible in the darkness; the air, being very much electrified, meeting the cloud, neutralized, it was thought, a portion of the fluid there. But the intensity of the electric current was enough to fuse the gold or platinum point, so that at the end of some time the sharp point disappeared, and was replaced by a large lump of the fused metal.

The preventive action of the sharp point, by promoting the quiet flow of the electricity under the form of a luminous plume, would then only endure for a limited time; but there was but little advantage even then. It is probable that the air, electrified by the brush discharge at the tip, instead of being moved towards the cloud to help to discharge it, was rather carried laterally by the wind. Such is the reason why we now give the preference to stems terminated by a cylinder, and a cone of copper. Nevertheless, we shall see later, that sharp acute points are preferred in a system of lightning conductors to multiple spikes.

When shaped thus the point of the lightning-conductor will rarely present the spectacle of luminous plumes; but, because of its form, and the great conductivity of copper, it will resist fusion much better, without being less efficacious in protecting the edifice. The essential thing is that the electric current, which passes from the cloud to the lightning-conductor when the lightning bursts forth, should find an uninterrupted path from the stem to the conducting subterranean nappe.

The metal bar serving as a conductor, and having, as we saw, a section of about fifteen millimetres in diameter, should be soldered with care to the stem (Fig. 351), which itself is solidly fixed to the top of the building. All its successive parts, horizontal, vertical, or inclined, should be connected together by curves, and soldered with the same care to the joining points. Its firmness must be maintained by iron supports, with prongs, which allow of the bar expanding longitudinally, without having any play sideways.

Sometimes rigid bars are replaced by twisted cables as conductors, composed of three or four strands of iron wire covered with tar to prevent rust. The conductor should never be formed of a metal chain; so says Pouillet in his supplementary instructions, published in 1854: "A chain is never admissible; it ought to be very decidedly excluded from all such use. Here are the reasons: the

links never touch one another except imperfectly, because of the oxidation of the metal surface and the various impurities that settle between their surfaces; and, even admitting that the surfaces of the points of contact are clean and metallic, they are always too small, so that even a feeble discharge, restricted as it is to these points, would suffice to fuse the iron, and even to burn it up."

It is necessary then to be sure that the communication of the cable with the stem takes place by the largest possible contact between the metal surfaces of the stem and the wires; which should be perfectly clean and soldered to the iron of the "stem."

Also, as an essential condition, all the metal parts of the building,

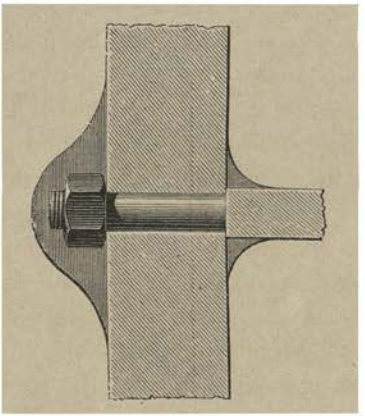

FIG. 351.—Connection of the vertical "stem" with the "conductor."

the lead ridges, the lead or zinc pipes, the roofs or floors of metal should be united together and communicate with the conductor.

We now come to the most essential condition, which if neglected would make a lightning-conductor instead of a protector against lightning, a most dangerous apparatus in stormy times. The conductor when it touches the ground, *must also penetrate it sufficiently deep to be in reliable communication with the subterranean sheet of water*. For that, a special well must be dug where, during the greatest drought, the water is at least a metre deep.

If near the conductor there are watercourses, streams, or rivers, large enough not to be dried up during drought, or lakes or large ponds, then it will suffice to put the latter in communication with the body of liquid.

Besides there is nothing to prevent the conductor from being put also into communication with the upper layer of the soil, which forms a supplementary reservoir, when sufficiently soaked with rain; but this would be altogether insufficient if not combined as an essential feature with a well into which the conductor dips with several

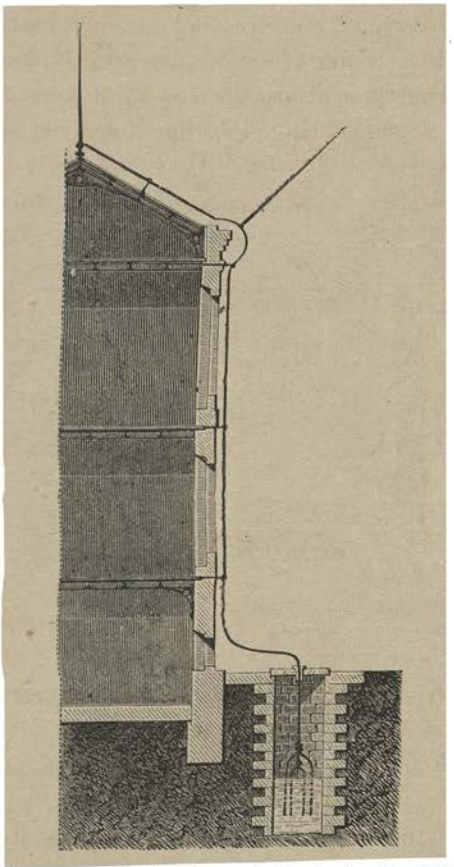

FIG. 352.—Arrangement of a lightning-conductor showing the earth-connexion.

branches, as shown in Fig. 352. When a side-branch is put into contact with the soil care is taken to surround it with a layer of cinders, which are good conductors of electricity, and tend besides to keep the iron from rusting.

The immersed surface of the conductor should be as large as possible. Experiments made by Pouillet and Becquerel showed that

the resistance of distilled water to the passage of electricity is at least 900 millions of times as great as that of iron. It is necessary then that the sheet of water into which the conductor dips should have a surface 900 millions of times as large as the section of the conductor for it to be safe; that is to say, the extent of the water should be 4000 square metres, supposing the bar of iron to be fifteen millimetres in diameter.

In point of fact the water of subterranean sheets is far from being pure; its conductivity far surpasses that of pure water, because of the salts that it holds in solution, and the immersed surface may be proportionately less.

Two engineers who have considered closely the conditions of

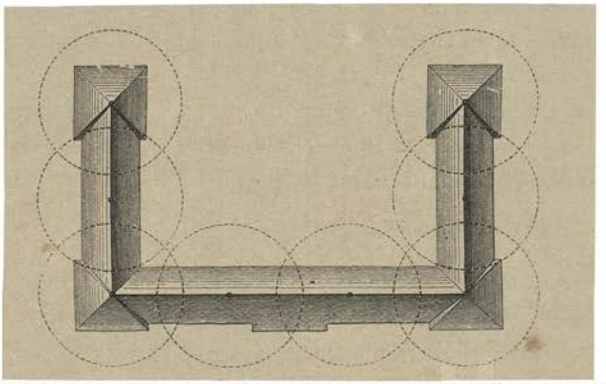

FIG. 353.—Limits of protection of a system of lightning-conductors on the roof of a building.

efficiency of lightning-conductors, Perrot and Callaud, have for some time past called attention to this delicate point. Numerous facts show the efficacy of lightning-conductors, but that this power should be real it is necessary that the apparatus erected should fulfil all the conditions above mentioned. The number of lightning-conductors also, and the height of the "stems," should agree with the dimensions of the buildings they are intended to protect. Experience shows that the higher the vertical "stem" is above the roof of the building, that is to say above the point of insertion of the "stem" with the conductor, the more considerable is the protecting sphere of action. Moreover the radius of this sphere is about equal to double the height of the stem. This being known it is easy to determine the number of "stems" necessary for any house or building.

Arago gives this general rule : " The less high the stems are, the more they must be multiplied. Their number will be sufficient when there is not, on ridge or terrace, &c., any point, the horizontal distance of which from the nearest stem is not more than double the height of that stem above its base."

Vertical lightning-conductors may suffice when the edifice is not high. In the contrary case the lateral parts need special protection, for there are examples of buildings struck by lightning on points much less elevated than their summits. Stems placed obliquely, or even horizontally, would have the effect of discharging the edges of clouds, which in stormy weather often descend to within a short distance of the ground, and against which the vertical points of lightning-conductors have no neutralizing action.

It is well known that oblique stems ought to have their conductors like the vertical ones. Moreover it would be advantageous to put all the stems of the lightning-conductors of the same building into communication by metal bars running along the top ridges; but as much as possible each should nevertheless have its separate conductor: many conductors can without inconvenience be led into the same well; but if you join many bars into one you must give that one a section large in proportion with the number of conductors that it replaces.

Among the buildings most necessary to preserve from lightning are warehouses which contain combustible or explosive materials, gun-cap factories, powder-mills, &c.

But then instead of surmounting the buildings with lightning-conductors it is better to surround them with poles of wood or pillars of stone, at the top of which rods are placed. The reason of this precautionary arrangement is easy to understand; it is not enough here to prevent the buildings from being struck, the conductors themselves must be kept out of possibility of contact with the buildings where dangerous materials are made or stored.

Ships at sea are very much exposed to lightning strokes from the form and height of their masts. So it is necessary to furnish them with one or more lightning-conductors, the vertical rods of which are fixed to the top of the masts. The conductors may be bars or metal cables joined to the rods, and going thence to the copper sheathing of the bottom of the vessel. The communication with the sea

through so enormous a surface renders effectual the protective action of this arrangement.

Sir William Snow Harris designed for lightning-conductors for ships a system of conductors which is adopted in the English navy, and which offers certain advantages over cables and metal bars, namely that of bending with all the movements and all the varied positions of the masts. This system consists of large sheets of copper enveloping the mast and communicating with the sheathing of the vessel.

The result is that in stormy weather, even when the masts are broken by the violence of the wind, the lightning always finds a system of conductors sufficient for the discharge of the electricity, rendering it harmless. Arago relates that the English frigate, the *Dryad*, was many times exposed on the coast of Africa to violent tornadoes. The ship was furnished with Snow Harris's lightning-conductors. The fulminating discharge descended in such continuous quantity that it produced a kind of luminous atmosphere, and a noise like water boiling very fast. The ship was however entirely preserved.

§ 3.—*Systems of Lightning-Conductors with Multiple Points.*

According to experiments carried out in 1862 by M. Perrot, the sharper the terminal point of the metal stem, the more considerable is its neutralizing action; also by multiplying the terminal points of a metal rod its neutralizing action is increased; but this action is only exercised in the region situated above a horizontal plane passing through each point. In giving an account of these experiments Professor Gavarret concludes from them that some modifications might with advantage be made in the construction of lightning-conductors. Here are the terms in which the Professor speaks of these modifications :

(1) The neutralizing action of the lightning-conductor would be more powerful by arming its upper extremity with a crown of points.

(2) The stem itself might be protected from lightning flashes thrown laterally upon it from the edges of storm-clouds beaten down by the wind, by arming this stem from top to bottom with a certain

number of side points conveniently arranged at proper heights. Such multiple points, while considerably increasing the quantity of electricity furnished by the lightning-conductor in a given time, would have the advantage of dividing the current. Each of them would be traversed by a current too feeble to melt them, even in the most violent storm.

Lightning-conductors with multiple points are now adopted in many countries, particularly in Belgium, where Glœsener and Melsens studied the best conditions for their erection on public and private buildings. According to Melsens, "instead of employing one long pointed stem with costly arrangements, it is better to have six or seven points, from 1 metre to 1·50 metres or 2 metres high, and to multiply the number of them on the conductors, which can be done at very little expense. In short, ten tufts in copper of 1 metre high would not cost as much, with their sixty or seventy slender points, as one stem on the old model; and if galvanized iron is used, worked up into a point, two or three hundred points dispersed over the upper ridge of a building in the form of tufts, with five, six, or seven points to each, would not cost more than one stem of middling height."

He says that he generally employs "tufts of very short points, from 0·50 to 1·50 metres, sometimes 2 metres in length, the apices of which are inclined at 45° and spread out like a fan or a basket round the central point, which is longer than the others; they are from 6 to 8 millimetres in diameter at their base. They may be made of copper or galvanized iron, or galvanized iron terminated by a slender point of copper, arranged like those recommended by the *Académie* for the large stems."

It is on this system that the Hôtel de Ville at Brussels has been furnished with a protecting system of points in numerous tufts surmounting the spire and all the salient parts, belfries, ridges, &c., and united by a network of conductors which inclose the whole edifice as in a sort of metal cage. Communication with the earth is also very widely established; the conductors end in a galvanized iron case, whence proceed three series of subterranean wires; one of the series ends in a well, the two others are joined to the water-pipes and the gas-pipes.

The monument of King Leopold at Laeken is protected by a similar system of points and multiple conductors; a model of this

was shown at the Exhibition of Electricity at Paris in 1881, and it was possible to examine upon it all the details of the application of Melsens's system.

In France the House of Correction at Nîmes is amongst the number of the public buildings where lightning-conductors with multiple points

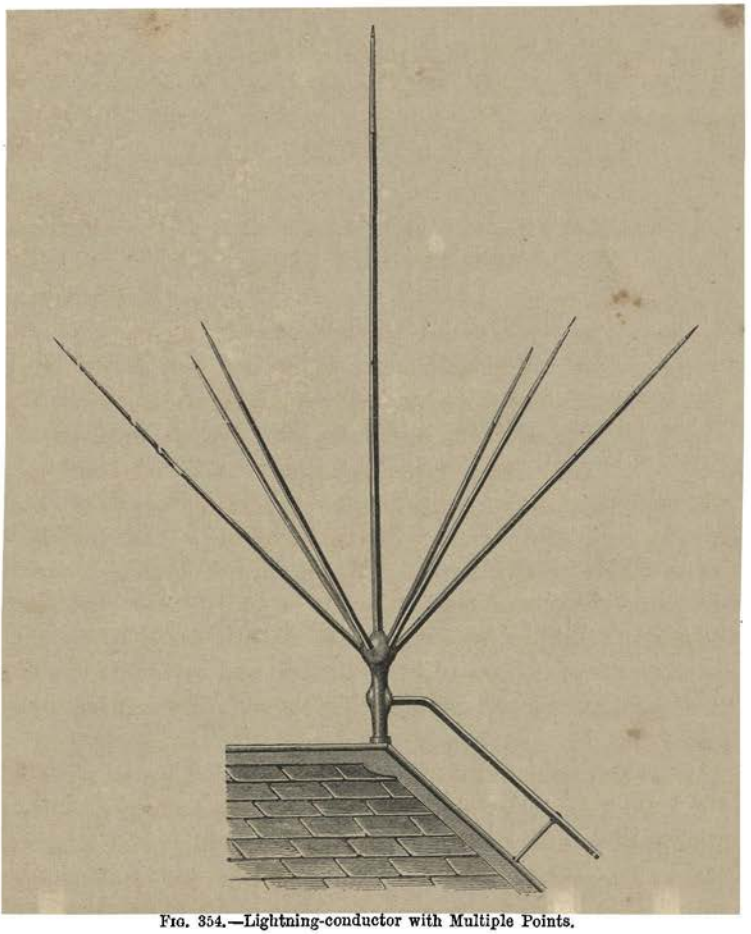

FIG. 354.—Lightning-conductor with Multiple Points.

have been adopted. A communication made on this subject in 1879 at the meeting of the provincial learned societies, held at the Sorbonne, gave rise to a remark by one of those present which we think interesting enough to reproduce. According to M. Alluard the system of lightning-conductors in question existed twenty years ago in the Puy

de Dôme, which shows that the invention goes back to a time three years before the communication mentioned at the beginning of this paragraph and due to Perrot.

[In England it is not usual to erect such huge "stems" on the tops of buildings as are described above by the author, who, of course, speaks for the practice prevailing in France. In this country the copper rod itself is usually simply carried a foot or two above the top of the highest point of the building, and either pointed itself or is supplied with some auxiliary lateral points. A round rod of copper half an inch in diameter is usually considered sufficient, though flat tapes are also used. At the Houses of Parliament at Westminster the Victoria and Clock Towers, each of which is 300 feet high, are each supplied with a copper tape 5 inches wide and half an inch thick; they are connected to the metal of the roof, to the iron rail of the staircases, and to earth. The most reliable authority on this subject in this country is beyond question the *Report of the Lightning-Rod Conference*, published in 1882. This Report was drawn up by a joint Committee representing the Meteorological Society, the Royal Institute of British Architects, the Society of Telegraph Engineers, and the Physical Society. They drew up (1) a statement of the purposes which a lightning-conductor is intended to serve; (2) a statement of those features in the construction of lightning-conductors with respect to which there is a difference of opinion, and their decisions thereon; (3) a code of rules for the erection of lightning-conductors.

The following is a brief summary of the code recommended. It will be noted that the conductor is treated as a single thing, no separate "stem" is recognized:—

The point of the upper end of the rod should not be more acute than a cone of 45° semi-vertical angle; but a foot lower down a copper ring should be screwed and soldered on, leaving three or four sharp points six inches long, preferably gilded or platinized. The rod is not to be insulated from the building by glass or other insulators, but attached to it by metal fastenings. Rods should be carried down the side of the house most exposed to rain. Factory chimneys should have all round the top a copper ring, armed with stout copper spikes a foot long, connected to the rod. All ornamental ironwork (also lead or zinc roofs and spouts) on the roof should be connected to the rod. Copper, tape or rope, weighing not less than

six ounces per foot run, or iron not weighing less than $2\frac{1}{2}$ lbs. per foot run, may be used for the conductor. Every joint besides being well cleaned, screwed, scarfed, or riveted should be well soldered. The conductor should be connected to all extensive masses of metal (hot-water pipes, for example) inside or outside buildings; but on no account to soft-metal pipes or to internal gas-pipes. It is essential that the lower extremity of the conductor be buried in permanently damp soil; a strip of copper tape may be soldered to the nearest gas or water "main." Lightning-conductors should be tested as to the goodness of their earth-connexion when erected.—ED.]

CHAPTER III.

ELECTRIC TELEGRAPHY.

§ 1.—*Invention of the Electric Telegraph.*

TELEGRAPHY, or the art of communicating at a distance, so as to transmit orders, news, instructions in a detailed and precise way, is quite a modern invention, a contemporary art, so to speak. From time immemorial various means have been used for transmitting signals rapidly to considerable distances: fire-beacons, fog-horns, the human voice transmitted from outpost to outpost, cannon shot semaphores and signals at sea, consisting of a combination of visible objects, all these methods rested on the rapid propagation of two physical agents, one much slower than the other, sound and light.

But it was only at the end of the last century that the improving of telegraphy was thought of, so as to use it in the transmission of government despatches, to assure the secrecy of these messages, as well as to give them the same precision as the language itself, Chappe's air telegraphs were adopted in 1793 by the National Convention, and soon after spread into all civilized countries. But, before they were even thought of, trials were made in quite a different direction: a new science, electricity, had come to reveal the existence of an agent that propagated itself with a speed comparable to that of light, and the idea of utilizing phenomena of this order for rapid communication was seen at once. Fifty years had scarcely passed before the electric telegraph was invented, and superseded the air one.

To-day, the metal wires which serve to transmit human thought with lightning speed, for the wants of commerce, politics, science, as well as for private correspondence, are spread over the whole globe.

They form a network of prodigious length, which covers not only continents, but which traverses oceans and seas, and unites all the nations of the world, from Europe to the Indies, Africa, Australia, America. From the American continent this marvellous chain will soon traverse the whole extent of the Pacific, to unite Japan and China, and thus complete the union of the terrestrial sphere. We will give statistics of the universal telegraphy later on. Let us now sketch the history of this marvellous invention.

To give this history in all its details would require a whole chapter, or rather a whole volume. It will suffice to mark rapidly the principal phases, and to show how these phases are bound together in the progress of the science.

Before the invention of the voltaic battery, the projects for electric communication, though very numerous, found no serious practical application. Lesage in 1774 transmitted frictional electricity by insulated metal wires to pith-ball electroscopes, the movements of which marked the letters of the alphabet: there were then twenty-four wires, one for each letter. Later, in 1798, Bethancourt substituted the discharge of a Leyden-jar for that from an electrical machine, and the system was applied between Aranjuez and Madrid over a distance of not less than 44 kilometres. It was a similar system that the French philosopher, Lomond, constructed in 1787. Reiser in 1794, Cavallo in 1795, Salva in 1796, and Ronalds in 1823, all made use of static electricity for signalling, modifying the mode of indication, for example, by employing sparks made on bright plates.

The discovery of the battery directed inventors into a more interesting direction, and one nearer to the true solution.

The American Coxe in 1800, Sœmmering in 1811, and in 1828 Schweigger, the inventor of the multiplier, had all successively utilized the idea of the chemical properties of the voltaic current.

Bubbles of oxygen and hydrogen, resulting from the decomposition of water, being disengaged at one of the stations, indicated different signals, which were produced at the station, at the far end of the conducting wires, by successive interruptions of the current.

Another advance of science, the discovery of the action of currents on the magnetic needle by Oersted, 1820, was the point of departure for new researches, which led at last to the end. In the same year as this grand discovery, Ampère defined this end, and indicated the

means of reaching it: this illustrious physicist said: You might, by means of as many conducting wires and magnetic needles as there are letters, and by the aid of a battery placed at a distance from the needles, and communicating alternately by its two extremities with those of each conductor, form a sort of *telegraph*, adapted to indicate all the details you wished to transmit through any intervening obstacles, to a person observing the letters placed on the needles. By fixing to the battery a key-board, the keys bearing the same letters, and communicating by pressure with the needles, an easy means of correspondence would be established, requiring only the time necessary to touch the keys on one side, and to read on the one instrument each letter that was signalled on the other.

Ampère's idea was not realized exactly as he described it; the number of galvanometers, each of which should correspond to a letter of the alphabet, would have been too considerable; but when we describe the electro-magnetic *needle* telegraph, we shall see that its construction is based on the same principle. It is to the Englishman, Wheatstone, that we owe the improvements and simplifications which have given to Ampère's conception all its practical importance.

But, before coming to a complete realization, this idea was applied in various ways; by Schilling in 1833, by Gauss and Weber in 1835, and by Ritchie and Alexander in 1837. The first applied it at St. Petersburg, but on a small scale. "Five platinum wires inclosed in a cable of silk were connected each at one end with a multiplier, and at the other with a key-board similar to that of a piano. A battery current was sent into one of the wires by pressing the key corresponding to it, and, according to the direction of the current, the *needle* moved to the right or left; thus forming with five needles ten different signs. In 1837, Ritchie and Alexander constructed at Edinburgh an apparatus on the same system. There were thirty needles, corresponding to as many wires between the two stations, and with an equal number of signs.

Gauss and Weber also employed this kind of apparatus to communicate between the physical cabinet and the observatory at Göttingen. In every case the current transmitted was of electro-magnetic origin: the deviations of the galvanometer needle to the right and left corresponded with the movements of a bobbin, bound to

the line-wires round a strong cylindrical magnet, whence came the currents alternately in contrary directions.

The time arrived (1837 and 1838) when the electric telegraph passed the period of attempts and trials to that of truly practical realization, and the names of Wheatstone, Steinheil, Morse, Masson, Breguet recall the important discoveries and improvements which characterize the different systems successively adopted.

§ 2.—*The Electric Telegraph: General Theory.*

We have seen that a piece of soft iron, round which is wound a coil, or spiral of insulated wire, constitutes an *electro-magnet*; that is to say a temporary magnet, the power of which lasts during the passage of an electric current in the coil, and ceases as soon as the current is interrupted. We also know that this temporary magnetism is instantaneous but increases gradually, and that it ceases with the same rapidity that it begins.

Hence if by any means whatever a current of electricity is passed through the coil of an electro-magnet and interrupted; when this operation is repeated rapidly, the attraction of the poles of the magnet for its armature will be reproduced, and cease as it is alternately magnetized and demagnetized. This property is made use of to obtain a continuation of alternate movements of the armature, for which it is provided with a spring, holding it at a short distance from the poles, without preventing contact every time that the current passes.

On this principle is based the construction of machines called *electro-motors*, because electricity is the source of the motion which they produce. This motion, which may be utilized in a purely mechanical way, as we shall see further on, serves to produce signals that can be transmitted with very great rapidity to considerable distances, thanks to the enormous speed with which electricity is propagated in a conducting wire. Such then, reduced to its greatest simplicity, is the most general mode of action adopted in the different systems of electric telegraphy.

However, in some of these systems the electric current acts, either directly on the galvanometer needles or indirectly through its

chemical or electrolytic properties. But, whatever may be the mode of action, an electric telegraph is always necessarily composed of the four following parts:—

First, an apparatus producing the current; usually this is a voltaic *battery*, but sometimes there is used a magneto-electric induction machine, or a *dynamo*.

Second, a transmitting apparatus forming *a circuit* or *conductor* of currents; this is the wire, or wires of the line uniting the stations of departure and arrival of the signals.

Third, an apparatus for producing the signals, called the *manipulator*, *transmitter*, *key*, or *sender*; it is this that the person sending the dispatches uses.

Lastly, a *receiving apparatus*, where the signals sent are reproduced at the arrival station: this is called the *receiver* or *indicator*.

We shall soon see that there are in an electric telegraph other secondary apparatus, such as bells or annunciators, relays, and lightning protectors.

Such are the principles of electric telegraphy as it has been used up to the present time. The number of systems which have been and still are in use in the universal network of telegraphs is very great. We can only describe the most common and the most original, that is, those which are distinguished by a characteristic idea, by special mechanism, or by a particular mode of signals. From this last point of view the different electric-telegraphs known may be classed under five heads.[1]

(1) *Needle Telegraphs.* In these the receivers are composed of magnetic needles under the immediate action of a current which circulates in the line-wire; the result is deflections to the right or left, which are the elements of the signals.

(2) *Dial Telegraphs*, whose receiver consists of a dial provided with an indicating needle, the movement of which is regulated by an

[1] [There is a most important sixth class not mentioned by the author, possibly because though universal in America and common in England it is not used in France, namely *Sounder Telegraphs;* in which the receiving apparatus merely indicates the signals by the sounds it makes. The usual sounder is constructed like the Morse instrument described below, but without the recording part of the apparatus. A needle instrument may also be used as a sounder by fixing right and left two little sonorous metal cylinders of different tone, against which the needle beats.—ED.]

electro-magnet, itself under the action of the current, alternately sent into the wire and then interrupted.

(3) *Writing or Recording Telegraphs,* in which the dispatch sent is traced in the receiver on a strip of paper which continuously unrolls; the lines figured or marked with ink are produced by a point, the motion of which is due to the making and breaking of the circuit.

(4) *Printing Telegraphs,* in which the dispatch is itself printed in typographic characters and wants no translation.

(5) *Autographic Telegraphs,* which reproduce not only the text but the facsimile even of the writing of the dispatch, so that signatures, drawings, &c., can be sent and reproduced in their original form. For this reason these apparatus have received the name of *pantelegraphs* (from the Greek *pan,* signifying *all*).

Now we will describe the details of the principal systems of telegraphy which we have just enumerated.

§ 3.—*Needle Telegraphs.*

The *Needle Telegraphs* which first stood the test of serious and practical experiment were invented by Wheatstone. At first this electrician employed five needles, which required six line-wires, counting the return wire. These needles were put in front across the middle of a lozenge, whilst the corresponding galvanometers as well as the wires were placed behind the frame. When, by the aid of the manipulator, the current was passed in different directions through two of the five galvanometers, their two needles were simultaneously deflected, placing themselves diagonally and pointing towards one of the letters on the frame. For example, the needles 1 and 4 (Fig. 355) pointing to the left top of the frame indicate the letter B; and when the current passes in the opposite direction through these two galvanometers, the needles point to the letter V at the bottom of the frame. When only one needle moves it points to one of the figures on the lower edge of the frame. Two similar dials united by five line-wires gave at once the same indications when the sender of the dispatch worked the manipulator. At rest all the circuits closed each other. By pressing on two of the buttons, 7 to 18, placed in the two horizontal rows, the current passes through

the two corresponding galvanometers after having traversed the line-wires and deflected the corresponding needles on the receiver. This system worked with success on the railway between London and Birmingham, but was replaced by something more simple. Wheatstone, in partnership with Cooke, soon modified it, reducing the number of galvanometers to two, and finally to one, thus producing the one and the two-needle telegraphs which were adopted on English telegraph lines.

Fig. 356 shows the external appearance of *Cooke and Wheatstone's*

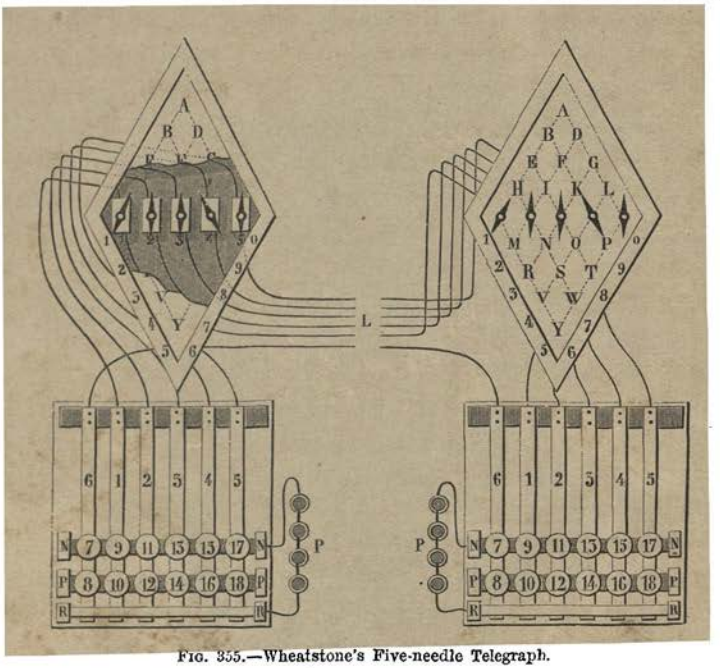

FIG. 355.—Wheatstone's Five-needle Telegraph.

single-needle instrument, which is identical at the sending and receiving stations. In front the galvanometer needle is visible, its deflections to the right and left are limited by the ivory buttons marked 1 and 3. Below this is the handle of the manipulator, which the sender turns to the right or left according to the deflection he wishes to produce. By combining the order and number of the needle's deflections to right and left, one, two, three, or four movements suffice to represent the letters of the alphabet, figures, and conventional signals.

The following was the English code:—

A	33	H	113	O	11	V	1311
B	1131	I	31	P	1111	W	1333
C	311	J	3133	Q	1313	X	3113
D	133	K	1331	R	333	Y	3111
E	1	L	331	S	111	Z	3131
F	313	M	1113	T	3		
G	1133	N	13	U	131		

The figures are indicated by the number and order of the movements of the lower point of the needle to right and left.

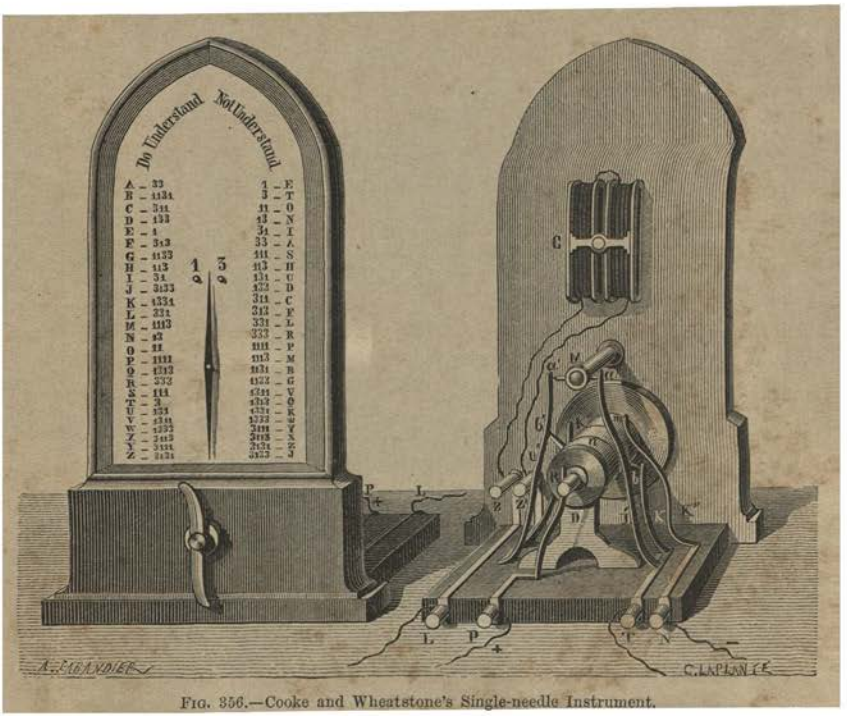

FIG. 356.—Cooke and Wheatstone's Single-needle Instrument.

The change from letters to figures and from figures to letters is indicated by a given signal. These combinations of signs are quite arbitrary: those adopted in Belgium (Fig. 357) with the same instrument were quite different.

The internal arrangements of Wheatstone's single-needle instrument as seen from behind are shown to the right, Fig. 356.

The galvanometer, G, is placed in the centre of the vertical plate. The indicating-needle is mounted on the same axis as the magnetic-needle of the galvanometer: they are moreover both magnetized, forming an astatic pair as in Nobili's galvanometer. What constitutes really the manipulator or commutator is placed below the galvanometer. It consists of a box-wood cylinder supported on two metal pivots on the axle with the exterior handle, and being able to turn like it to the right and left. The outside of this cylinder is covered by two metal leaves, *m n*, insulated from each other. The pivot D is always in contact with the spring R, and also with the leaf *n*. Two metal points, *b* and *b'*, project from the leaves, and, according to

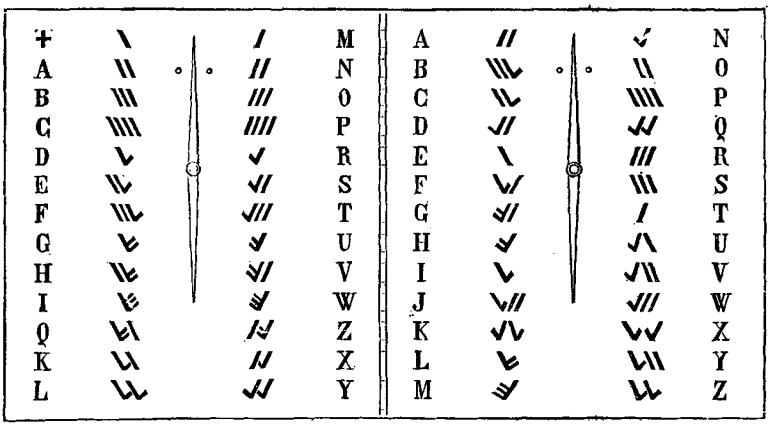

FIG. 357.—Belgian and English Alphabets of the Single-needle Telegraph.

their position, terminate the first against the spring K, the second against the spring U. The leaf *m* is in permanent contact with the spring K''. The pin M is furnished laterally with two points, *a* and *a'*, which touch either the spring U' or the spring U, according to the position of the handle. Lastly, the galvanometer coil is joined to the two terminals Z and Z'', which are connected, the first to the terminal L of the line-wire, and the second to the springs U' K' and the positive pole of the battery; on the other side the springs K and U are joined to the earth-wire T, whilst K'' is to N the negative pole of the battery.

Now, suppose the handle of the manipulator to be vertical. The points *b b'* are vertical, and the metal parts of the cylinder remain

insulated; the current from the battery cannot pass from one to the other, and consequently cannot traverse the galvanometer coil. If the handle be turned to the right, as in Fig. 356, the two points *b* and *b'* rest against the springs K and U', keeping back the latter from contact with the piece M. The current will then follow the path P R D *n b'* Z' G Z L; the current which thus enters the line-wire, after deflecting the upper point of the galvanometer needle of the sending instrument to the right, passes along the line to the receiving apparatus, deflects its needle in the same direction, and then escapes to earth. The earth serves as return wire, so that the circuit is completed to the negative pole of the battery at the sending station through the pieces T K *b m* K'' N. On the other hand, when the handle is turned to the left, the direction of the current is reversed by the points *b* and *b'*, the first resting on the spring K', the second on spring U, which it at the same time separates from the piece M. The path then followed by the current is marked by the series of letters N K'' *m b* K' Z' G Z L, the line, then T U *b' n* R P; and the needle of the sending instrument moves to the left, as well as that of the receiver. In this system the voltaic current traverses at the same time and in the same direction the galvanometer coils at the two stations, and it is interrupted simultaneously in both. The signals sent are thus reproduced at the same instant.

The *Double-needle Telegraph*, by the same inventors, is based on the same principle. Each instrument at the sending and receiving stations consists of a double galvanometer and a double manipulator, independent of one another. The sender turns the two handles which move the manipulators to the right or left, separately or simultaneously, so as to produce the signals which constitute the alphabet and figures shown in Fig. 359. At the top of the apparatus (Fig. 358) there is a bell, which serves to announce the sending of a message. Two metal bands on the side are used to put the bell in communication with the line current. The telegraphist, once warned, answers by a known signal that he is ready to receive, then he turns the handle shown on the side of the apparatus, so as to stop electric communication with the bell, and prevent it sounding whilst he is receiving the message. The dial underneath the handles of the manipulators is furnished with a needle, which, according to its position on the dial, separates such or such a station along the line

from the action of the current, or divides the line into two independent parts. This is what is called the silent apparatus. Thanks to this commutator you can stop telegraphic communication at stations not directly interested, and the service may continue independently between all the others.

In the double-needle telegraphs, as in the single ones, the movement of the needle is limited by two little ivory pillars, which

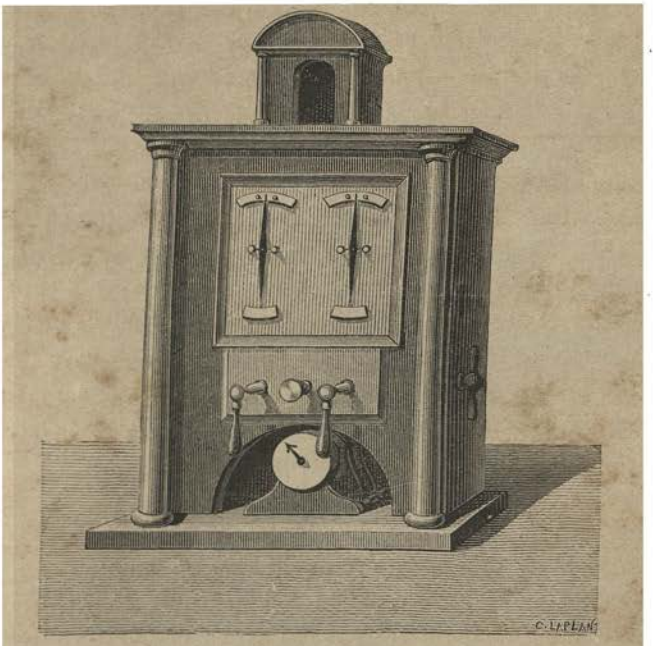

FIG. 358.—Double-needle Instrument.

also serve to tell the ear the number of taps by the sharp sound of the needle on the ivory.

Other inventors have constructed systems of needle telegraphs, which have worked with success.

First there is the double-needle telegraph of Glœsener, merely a modification of Wheatstone's. The difference consists principally in the addition to the multiplier of the receiver of two electro-magnets, each of which reacts on a different pole of the three magnetic needles composing the galvanometer. The magnetizing coil of these electro-

magnets is the continuation of the multiplier. According to Glœsener this addition doubles the force of Wheatstone's apparatus.

Bain's Single-needle Telegraph depends on a different principle from those already described. There is an electro-magnet whose bobbins react on two permanent magnets in the form of semicircles, movable round an axis which bears the indicating needle. The simultaneous attractions and repulsions in one direction or the other produced in the poles of the electro-magnet and of the permanent magnets by the passage of the voltaic current, cause the needle to move to the left or bring it back into its vertical position. The manipulator is a simple commutator for reversing the poles, and is

Needle to the left.		The two needles together.			Needle to the right.	
+	\	R or 8	\	\	\	H or 4
A	\\	S	\\	\\	\\	I
B	\\\	T	\\\	\\\	\\\	K
C or 1	\	U or 9	\	\	\	L or 5
D or 2	✓	V or 0	✓	✓	✓	M or 6
E or 3	/	W	/	/	/	N or 7
F	//	X	//	//	//	0
G	///	Y	///	///	///	P
		Z	/	\		
		Q	\	/		

FIG. 359.—Alphabet of the Double-needle Telegraph.

worked by a handle: spiral springs bring it back to a vertical position. Bain's telegraph has been in use since 1846 on the line from Edinburgh to Glasgow.

Henley's Needle Telegraph is worked by a magneto-electric machine. An electro-magnet turns before the poles of a strong permanent horse-shoe magnet. By pressing an ivory button with the finger, an induction current is set up in the line and receiver, and as soon as the finger is raised, a second current is produced in the opposite direction. The receiver is itself an electro-magnet furnished with two pieces of soft iron at its poles, and between these pieces in the horse-shoe is placed the magnetic needle, whose deviations are repeated by a parallel indicating needle, mounted on the same axis.

The signals in Henley's system are similar to the Morse, which is given below (page 602 *et seq.*).

Foy and Breguet designed a system of needle telegraph, the object of which was to reproduce the signals of Chappe's telegraph. This system has been worked since 1845 on the line from Paris to Rouen (145 kilometres), and has given, it seems, excellent results. Like Wheatstone's double-needle telegraph, it requires two line-wires; but the inventors have constructed some apparatus with a single needle, requiring only one wire, and still giving from 100 to 120 signals a minute. Fig. 360 represents the *receiver*, which consists

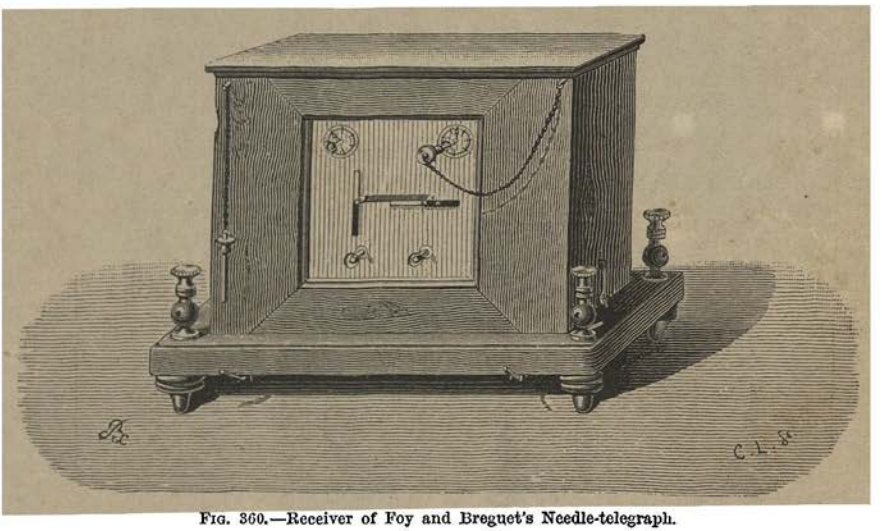

FIG. 360.—Receiver of Foy and Breguet's Needle-telegraph.

of two symmetrical and independent pieces of apparatus, each corresponding to one of the indicating needles. Each needle, one half black, and the other half white, can take eight positions round its centre, two horizontal, two vertical, and four at 45° to the others, which gives sixty-four different signals. The mechanism of the receiver is much the same as that of Breguet's dial-telegraph described below (page 590). By turning the handle M (Fig. 361) of the *Manipulator*, which is double, and putting it in one of the eight positions corresponding to the eight notches on a fixed wheel, moves another wheel mounted on the axle of the handle, on the plane of which is a deep and sinuous groove. The spring BC then

takes either the position seen in the figure, where the piece l touches the metal piece v, or a position nearer to the centre; l in that case

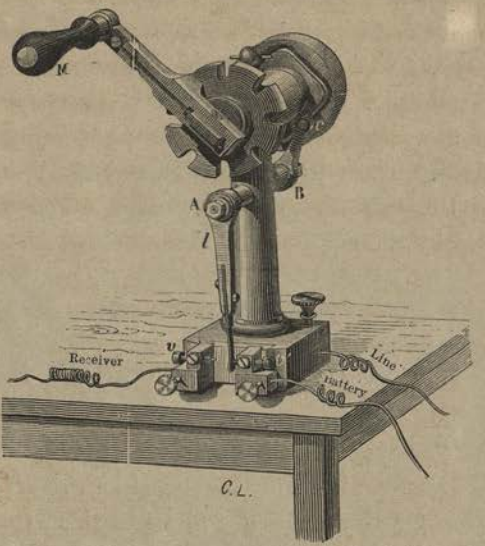

FIG. 361.—Manipulator of Foy and Breguet's Needle-telegraph.

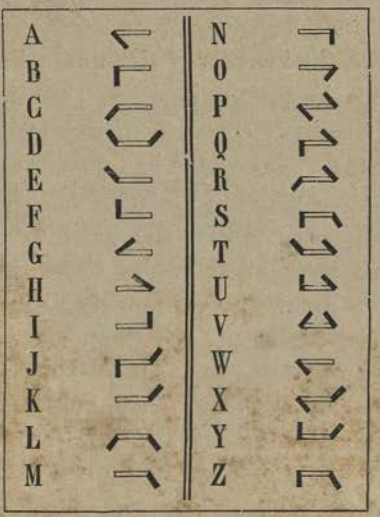

FIG. 362.—Alphabet of Foy and Breguet's Needle-telegraph.

touches the left hand piece v'. The two pieces v and v' are insulated by a piece of ivory at the metal part of the manipulator, where the

wires from the battery, line, and receiver terminate. Thus the making and breaking of the circuit produces movements in the receiver corresponding to those of the indicator needle.

Fig. 362 shows the alphabet which was adopted for the French needle-telegraph. The horizontal line is common to all signals, and requires no operation. Seven letters, A, B, C, E, F, G, W, only require the action of the manipulator to the left; six letters, H, I, K, M, N, O, only to the right. The thirteen other signs require the simultaneous movement of the two manipulators. This system has for a long time been used by the managers of French telegraphic lines.

§ 4.—*Dial Telegraphs.*

BREGUET'S SYSTEM.

The *Dial Telegraph* is chiefly employed on French railways. The principal reason for the preference given to this system consists in the facility of working the apparatus, which any workman on the line is able to do for sending and receiving dispatches, after a very short apprenticeship.

Wheatstone was the inventor of the first telegraph of this kind: the first trials made in France, in June, 1844, were on the railway from Paris to Versailles. Since then, a great number of similar systems have been tried or adopted in different countries.

Breguet's system is derived from Wheatstone's dial telegraph.

Figures 363 and 364 represent the manipulator or *transmitter*.

This is a brass dial supported by three metal columns on a horizontal wooden base. Two concentric zones, each divided into twenty-six sections, represent, one the twenty-five letters of the alphabet and a cross, the other the successive numbers from 1 to 10, and special signals. Instead of the latter signals there were the numbers from 10 to 25 in the old pattern (Fig. 364). On an axis through the centre of the dial is arranged a handle M which can be turned round only in the direction of the hands of a clock, and can stop at any of the letters or figures marked. For this purpose the handle has a pin which catches in the notches on the circumference of the dial in the middle of each of the twenty-six sections.

As the handle is turned it moves round a wheel, with a sinuous or wavy groove, which can be seen in the figure where the dial is supposed to be taken off. There are the same number of undulations in this groove as divisions on the dial, that is, there are thirteen crests and thirteen hollows corresponding to the letters or figures. A bent lever T, with fulcrum at *a* (Fig. 364) bears a little stem on which rolls a ball of tempered steel. The movement of the wheel is communicated to the ball which enters the sinuous groove, so that the end of the lever is sometimes near, and sometimes

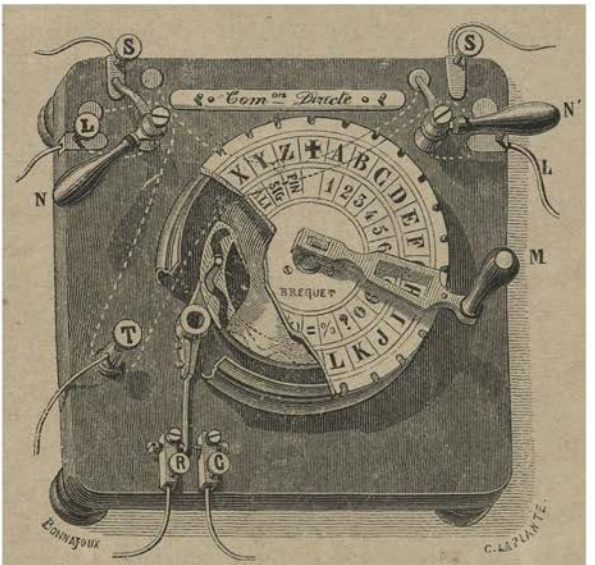

FIG. 363.—Breguet's Transmitter.

further from the centre, executing thus as many oscillations as there are divisions on the dial, over which the handle is moved.

The wire which comes from the positive pole of the battery joins the terminal R', which is connected by a metal strip to the screw P. Opposite this is another screw Q, which communicates in the same way with a terminal R, where the wire from the receiver terminates. It is between these two points P, Q, that the arm of the lever T plays, touching the one or the other. Let us suppose the transmitter at rest, or its handle on the cross, as indicated in Fig. 364. In this case the current does not pass, the circuit not being closed, and it is

the same every time that the lever is in this position, or when the handle passes over an even division on the letters B, D, F, or the figures 2, 4, 6. If on the contrary the handle passes before an odd division, the current enters by the lever T into the movable wheel of the manipulator.

The line-wires end at the two little metal tongues L and L′ which communicate permanently with two spring commutators r and r' that can be turned by the aid of a handle, the springs of which can be placed at will on the tongues S m, S′ m', or on the ends of the metal strip C D across the top.

If you wish to communicate with the telegraph station on the

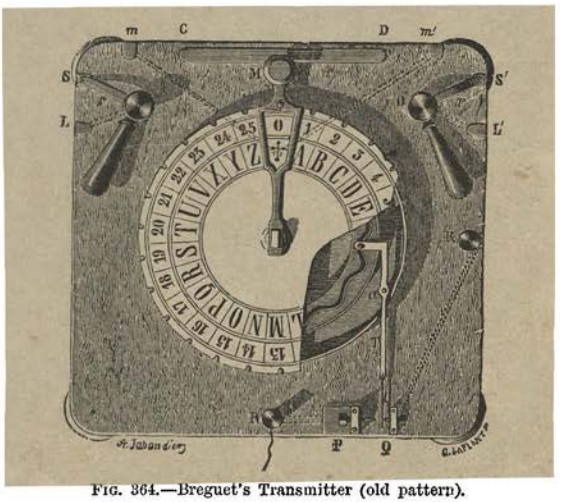

FIG. 364.—Breguet's Transmitter (old pattern).

left, you place the spring of the commutator r on m; if to the right, the spring r' is put on m'. The two pieces m and m' are in metallic connection with the movable wheel of the manipulator. Then, if the current from the battery enters the manipulator it passes by m, the spring r, the terminal L and the left hand line-wire. The current is sent into the line, arrives at the receiving station, thence into the earth-wire of this station, and returns by earth to the negative pole of the battery at the sending station. The same takes place on the right hand line, if the spring has been placed on the little tongue m'.

Now if you rotate the handle of the manipulator through one

complete turn there will have been thirteen passages of the current in the line-wire, and alternately thirteen interruptions. Let us suppose that it is required to send the word Paris, that is to send the five letters P, A, R, I, S. After a pre-arranged signal, the sender turns the handle from the cross to the letter P, and there he fixes it an instant, into the corresponding notch, and afterwards finishes the circuit of the letters up to the sign of the cross. Proceeding past this he stops the handle at A, completing the circuit to the cross again, and passing on to the letters R, I, S, in the same way.

At each circuit the number of currents and interruptions is twenty-six, but there is a pause corresponding to the moment when

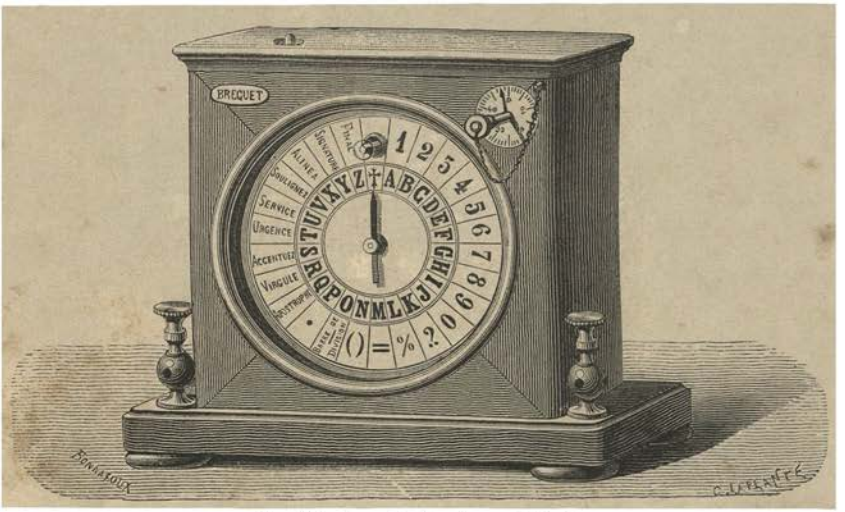

FIG. 365.—Breguet's Receiver or Indicator.

the handle rests on the letter that is being sent. These currents, interruptions, and stoppages are reproduced in the same order at the receiving office, on the dial of an apparatus, the needle of which reproduces exactly the movements of the handle.

Fig. 365 represents the exterior of the *receiver*. It is a box with a dial having the same divisions as the transmitter. Inside is clockwork, the escapement wheel and the needle of the dial being on the same axis, so that every time a tooth of this wheel escapes, the needle passes over a division. The current sent through the line by the transmitter of the sending office arrives at one of the

terminals seen on the base of the receiver, traverses the coils of an electro-magnet, placed at the lower part of the receiver, acts on a peculiar mechanism, and goes to earth through the other terminal. The action of the current and electro-magnet on the escapement wheel, in sending the signals, letters, or figures, and reproducing them on the dial by means of the needle may be seen from Figs. 366 and 367, which represent the mechanism of this receiving instrument. On the base there is the electro-magnet, through

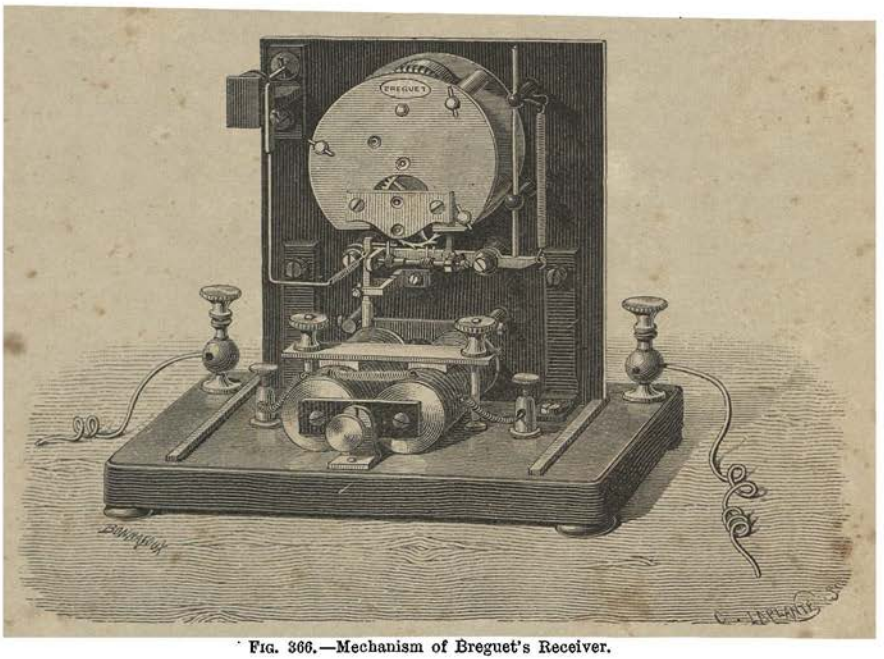

FIG. 366.—Mechanism of Breguet's Receiver.

whose coils passes the current sent into the line at the sending office. Opposite its poles there is a soft iron bar or armature M, supported by two screws, between which it can oscillate round its upper horizontal edge. When the current passes, it is attracted by the poles of the electro-magnet, and rests against them. When the current is interrupted, it is detached from these poles and pulled by a spring r towards the face of the receiver, where the dial is placed. It is this to and fro motion of the bar M which is communicated by a peculiar mechanism to the indicating needle. For this purpose it has a

vertical stem L which oscillates with the bar, but in an inverse direction, Fig. 367. This stem, limited in its motion by two screws, carries a pin *e* which fits into a fork *f*, so that the latter oscillates backwards and forwards communicating its motion to a shaft *b a*, and consequently to the little pallets *pp'*, which control the action of the escapement wheel R.

Suppose the receiver at rest, the indicating needle being on the cross, the pallet *p'* engages the tooth 1 of the wheel; the clock-work is fixed. The current passes as the needle of the transmitter advances from the cross to the letter A, the current

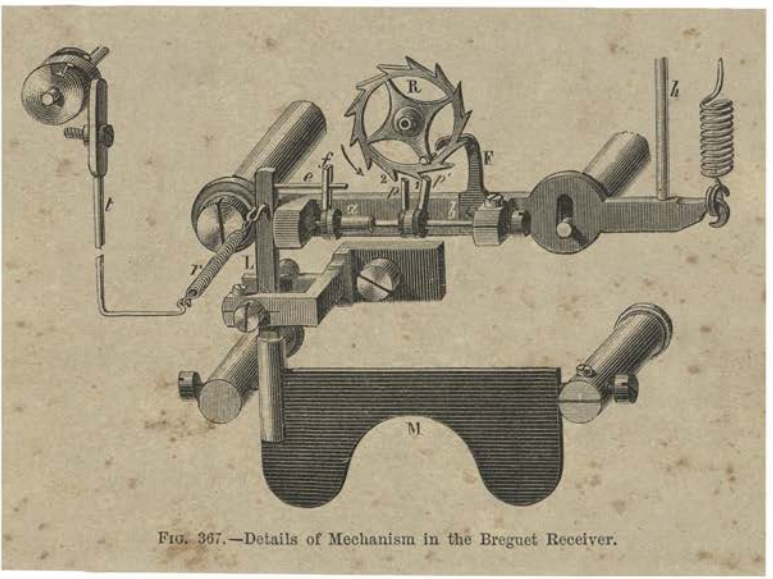

FIG. 367.—Details of Mechanism in the Breguet Receiver.

through the line enters the receiver, and then round the electro-magnet which attracts the bar M. This movement allows the shaft *a b* to rotate in a contrary direction with the pallet *p'*, which allows the tooth 1 to escape, and the pallet *p* becomes fixed against the tooth 2, when the clock-work, which is put in motion by the escapement, has turned the wheel. The indicating needle has advanced one division and stops on A. When the current ceases the spring *r* brings the armature back to its original position; the pallet *p*, lets the tooth 2 escape, the clock-work goes on again, and the pallet *p'* in its turn stops the tooth 2, the needle having passed a fresh division.

A very simple arrangement allows the return of the needle to the

cross without the passage of the current. By means of a rod h, seen to the right, you can lower the shaft which bears the pallets; these being free from the teeth of the escapement wheel, the clock-work moves, till a pin F meets a stay, conveniently placed, which corresponds in position with the needle on the cross.

The little dial (Figs. 365 and 366) on the upper part of the receiver serves to regulate the spring r. If this spring were not conveniently tightened, the bar might oscillate too far or too little; in the first case the pallets would come away from the plane of the

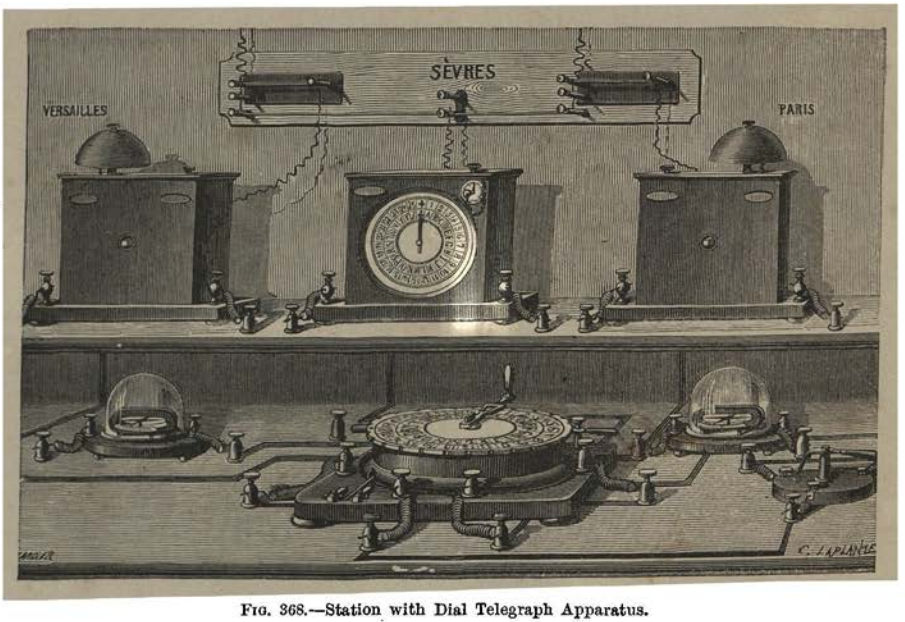

FIG. 368.—Station with Dial Telegraph Apparatus.

escapement wheel, and the clock-work would go without interruption; in the second case the pallets could not move from the teeth, and escapement would not take place: thus the receiver would not work.

Now, to show the arrangement of apparatus, take as an example of an intermediate station, the office at Sèvres, on the telegraphic line from Versailles to Paris. Fig. 368 represents the sending and receiving apparatus. The transmitter is fixed on a table, and on each side of it galvanometers which indicate the passage of currents

in each line-wire. Over these, on a shelf is arranged the receiver with an alarum bell on each side, which gives warning of a despatch from Paris or Versailles.

The apparatus being at rest, the little handles of the commutators remain on S and S′ (Fig. 364), terminals of the wires to the two bells. If the attendant at the Paris office wants to send a despatch to Sèvres, he turns the little handle of his transmitter once round. The current thus sent into the line enters the office at Sèvres by the left-hand wire, deflecting the needle of the galvanometer and acting on the left-hand bell. Warned by the alarum, the clerk puts the commutator on the right-hand to the terminal m'; then, turning the handle of his transmitter similar to that of the indicating needle of the receiver at Paris: in this way he announces that he is ready to receive the despatch. When the despatch is received, the office at Sèvres sends in its turn the two letters CO (*compris*, understood). To send *figures*, the signals are preceded by the two letters CC.

Now suppose that the Paris and Versailles offices wish to communicate directly. The sending office signals to Sèvres the name of the station to which he wants to send the message, followed by the number of minutes necessary for his message. The clerk at Sèvres answers CO (*compris*, understood), and then puts his two commutators on the plate, CD, for direct communication. All correspondence is interrupted at the office during the time that the despatch passes, and this is shown by the galvanometers. The despatch being finished, the clerk turns his commutators into contact with the bells.

DIAL TELEGRAPHS.

§ 5.—*The Siemens and Halske.—Froment.*

Besides the above-mentioned systems of dial telegraphs, we shall merely enumerate the following:—

Drescher's system has a transmitter in the form of a disk, divided into sections, alternately conductors and insulators, set in motion by clock-work. The motion is stopped by pressing that one of the twenty-six keys of a dial corresponding with the letter to be sent. The needle of the receiver stops on the same letter.

In *Paul Garnier's* system the dials, transmitter, and receiver are movable; the signals, letters or figures, appear simultaneously in two openings or notches on the circumference.

Mouilleron's dial telegraph system has a special mechanism which serves to regulate the tension of the spring in Breguet's telegraph.

Glœsener constructed many systems of dial telegraphs, but their principles would be too long to indicate here.

Lippens' system is peculiar in that it works by the aid of magneto-induction currents, an application that had before been made with telegraphic apparatus by Gauss and Weber in 1835, by Steinheil at Munich, by Wheatstone in 1840, and in 1848 by Glœsener.

There is also the *Kramer's* system, and the screen system by *Regnard.*

The *Siemens* and *Halske* system, constructed for the Bavarian telegraph lines, has been employed on the lines of the Society of Russian Railways, at London, Dantzic, and Königsberg, by the Fire Brigades, and on different English lines. The apparatus is worked by permanent magnets, the poles being surrounded by a cylinder of soft iron wound with insulated wire forming the magnetizing coil. The rotation of this cylinder on its axis generates induced currents, alternately, in contrary directions. These currents sent into the line one after the other, act on the electro-magnet of the receiver, causing the bar to oscillate, and thus acting on the escapement wheel bearing the indicating needle. Fig. 369 gives an outside view of the complete apparatus. A is a drum or cylindrical case containing the sending apparatus, or transmitter, and B is the receiver. M O is the handle which the sender turns, stopping successively on the letters of a dial as he desires. The needle of the receiver B follows all the movements of the handle of the transmitter.

A (Fig. 370) is the metal disc that supports the dial: twenty-six notches on its edge correspond to the twenty-six divisions serving as stopping points to the handle. A cog-wheel on the spindle O O′ gears into the pinion H. When this wheel advances one twenty-sixth of its circumference, that is, when the handle passes from one letter to the next, the pinion and cylinder C C make half a complete turn. Some permanent magnets *a a a*... are fixed to the iron column B B by their poles of the same name, arranged in two sets, one with

the north pole to one side of the cylinder C; the other series has the south pole to the other side of the cylinder. On this

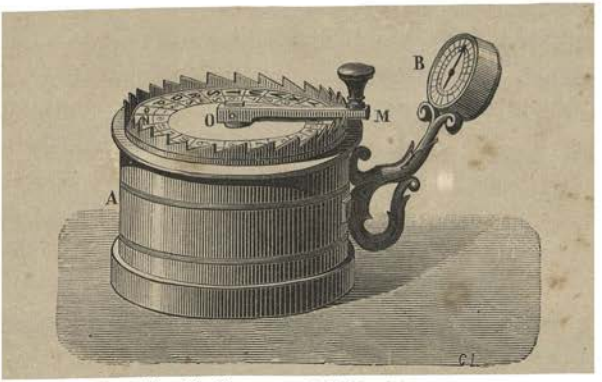

FIG. 369.—The Siemens and Halske Dial Telegraph.

soft iron cylinder C is wound the magnetizing coil, and it is by rotating and presenting alternately one or other of its faces

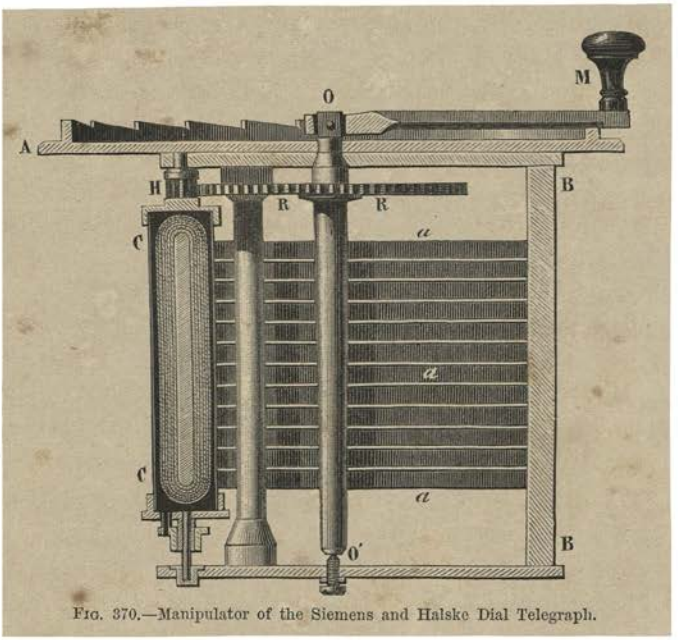

FIG. 370.—Manipulator of the Siemens and Halske Dial Telegraph.

separated by the coil, to the poles of the magnets *a* that the induced currents are generated, and sent successively into the line. For each

revolution of the cylinder C two currents are generated in opposite directions. Fig. 371 represents the mechanism of the receiver underneath the dial. M M′ are the two electro-magnet coils traversed by the currents from the line; P P′ are the two poles of this electro-magnet. Between these poles passes the branch *a* of a soft iron fork *b b′*, which is constantly magnetized by contact with the poles of the permanent magnet A A′. The result is that, according to the direction of the current sent, the branch *a* is either attracted by the pole P and repelled by P′, or attracted by P′ and repelled by P. There are twenty-six of these oscillations for one complete turn of the transmitter handle. Each swing releases one of the twenty-six teeth of the wheel R, and consequently the dial needle, mounted on the same spindle, advances one division.

FIG. 371.—Siemens and Halske Receiver.

In *Froment's* dial telegraph the receiver is the same as in Breguet's, but the transmitter is distinguished by a peculiar mode of making and breaking the currents. It is a wheel with a sinuous groove, B (Fig. 372), which in rotating oscillates a lever A, one of the arms following the sinuosities of the groove, whilst the other arm of the lever serves to make and break the successive currents. The wheel B is driven by clock-work and moves when the tooth on its circumference is released by the catch *e*. This is done by a key-board, each key corresponding to a letter or figure. On pressing down one of these keys a bar raises the catch, and the clock-work makes the wheel rotate at a speed of two or three revolutions per second. A metal cylinder D E under the key-board turns with the wheel B on the same spindle. This cylinder is provided with as many pegs as there are keys, forming

two series ranged in spirals; each peg corresponds to one of the keys, and its angular position on the cylinder depends on the order of the corresponding letter on the dial. When a key is pressed down a tooth under it knocks against the corresponding peg as soon as the cylinder has turned to the corresponding letter. Then it stops, and the number of times the current is interrupted agrees with the order of the key or the letter. The receiver needle has also passed over the

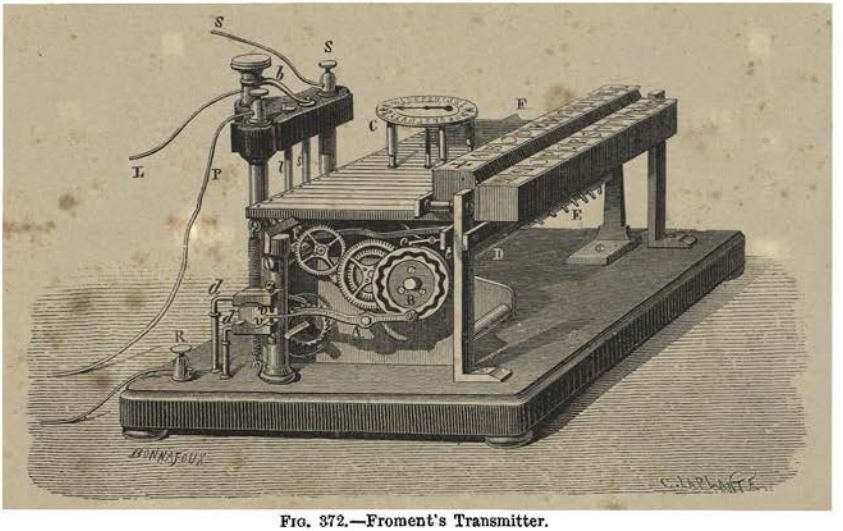

FIG. 372.—Froment's Transmitter.

same number of divisions and stopped on the letter sent. The key being liberated the catch *e* falls, engaging the tooth of the wheel B till another key is pressed down. The needle of the dial above the key-board moves with the transmitter and serves as a check to the clerk who sends a despatch.

Froment constructed some apparatus without clock-work; those with it are intended for long line working, but both are found to act with surprising precision.

CHAPTER IV.

THE ELECTRIC TELEGRAPH.

§ 1.—*Recording Telegraphs.—Morse, Morse-Digney Telegraphs.*

NEEDLE and dial telegraphs such as we have described form very numerous systems, each of which has its advantages and disadvantages. The former, being very simple in construction, require only feeble currents, but they are very sensitive to outside disturbances. The second, with much more complicated mechanism, have the advantage of easy manipulation. Both have one serious inconvenience: they leave no trace or record of the despatches to permit of accuracy being proved in case of false interpretation, disturbing

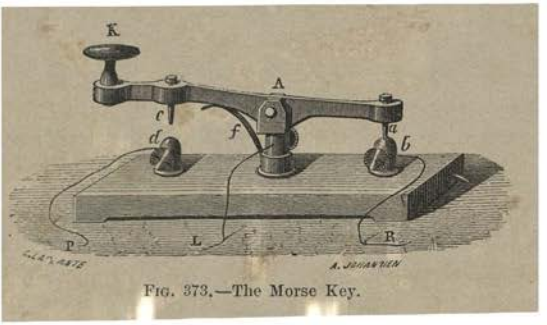

FIG. 373.—The Morse Key.

influences, or fraud; whereas the various kinds of apparatus we are about to describe print the despatch, at departure as well as at arrival, on a strip or riband of paper, which thus preserves the trace of the text sent and received.

The *Morse*, invented by Professor Morse about 1838, is the type of recording telegraph most widely used on account of the simplicity of its mechanism and the certainty of its indications.

The *key* or sending apparatus, represented in Figs. 373 and 374, is composed of a base of hard wood, on which are fixed two terminals *b* and *d*, and between them a short, forked column, upon which a lever

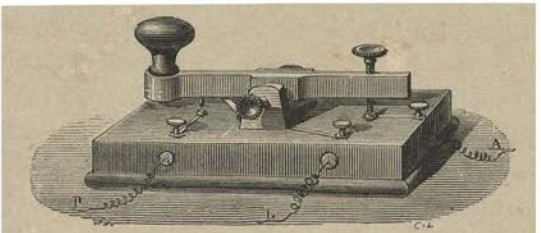

FIG. 374.—The Morse Key; another form.

A is mounted. The battery wire P is connected to *d*; *b* communicates by the wire R through the receiver or indicator on to earth, and the line-wire L comes to the middle column. The lever A has at

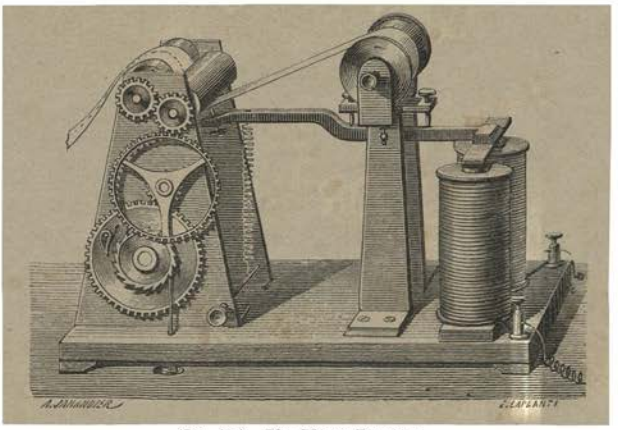

FIG. 375.—The Morse Receiver.

its ends two screws *a* and *c*, which can make contact with *b* or *d*. When at rest the spring *f* keeps *c* separated from *d*, and *a* in contact with *b*. In this position currents from the line-wire pass by L into the lever of the key by *a* and *b* to the receiver. In sending a

despatch the handle K of the lever is pressed down to overcome the spring, to separate *a* from *b* cutting the receiver out of circuit, and to bring *c* into contact with *d*. Then the current passes from P through the key into the line-wire L, and is interrupted by raising the key.

The receiving instrument or indicator (Fig. 375) consists of an electro-magnet, one end of the magnetizing coil being connected to the line-wire and the other to earth. As the key is pressed down at the sending office, the current sent through the line to the receiving offices magnetizes the soft iron of the electro-magnet attracting the soft iron armature carried at one end of a lever, which is pulled back by an opposing spring when the current ceases. The movement of this lever round a horizontal axis is limited by two screws. At

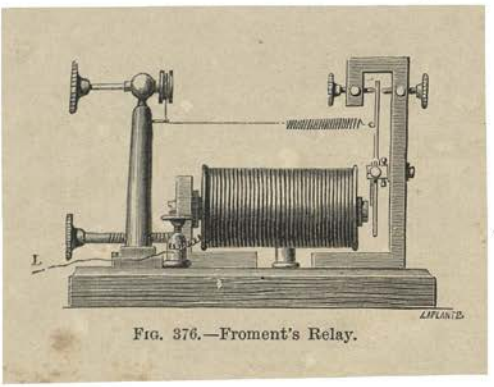

FIG. 376.—Froment's Relay.

the other end of the lever there is a point which presses on a strip of paper, marking it whilst the current is passing. The intervals between these marks represent the interruptions of the current. A train of clock-work, put in motion at pleasure by a spring, drives a pair of rollers, which draw the strip of paper past underneath the pen so that it receives the series of marks which make up the message. If the current is momentary a *dot* is made on the paper, but if the current flows for a longer time a *dash* is produced of about three times the length. At first a pencil was used to trace the marks on the paper, but the point soon became blunt, so that a metal point was substituted.[1] This method demanded a force which the battery current

[1] Both paper and inking roller as well as the clock-work are dispensed with in the *Sounder* which is extensively used in this country and America. In the

from the line was generally too feeble to produce. Hence the necessity of employing at the receiving station a local battery and a relay.

A *relay* (Fig. 376) is an apparatus which sends a strong local current through the receiving instrument when actuated itself by a feeble line-current, which may be sufficient for the transmission of signals, but not strong enough to mark the paper. The feeble current arriving by the line-wire at *c* (Fig. 377) passes through the key to *a*, then by a wire to the electro-magnet coil of the relay R′,

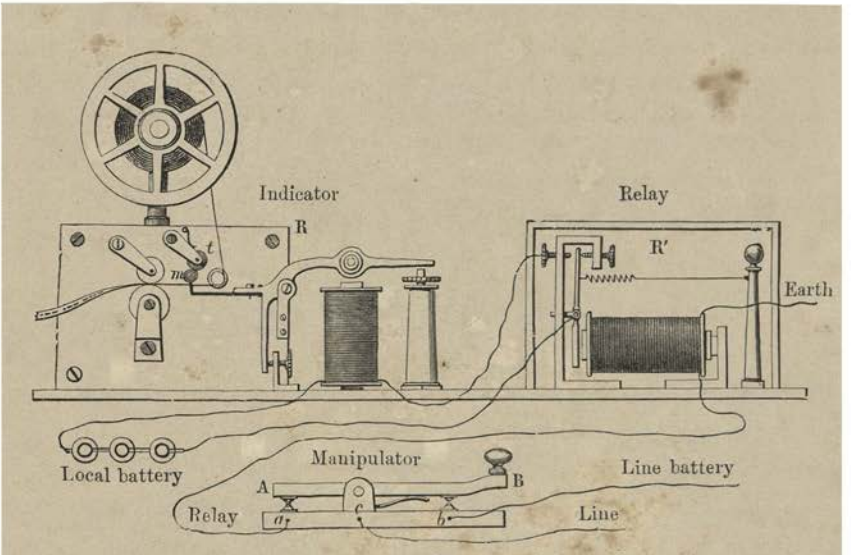

FIG. 377.—The Morse Apparatus, with Relay.

and through this coil to earth. The electro-magnet of the relay attracts an armature or movable lever, making contact with the screw to the left and thus completing the circuit of the local battery, which sends a strong current through the coil of the electro-magnet of the receiver R, and thus works the writing lever. If the line-current is interrupted the action of the relay electro-magnet

most common type the sound is produced by the tapping of the lever against two metal stops or brass pieces between which the end of the lever works. As the armature rises and falls the signals are indicated to the ear by the taps against the stops; a short interval between the sounds representing a "dot" and a longer or more sustained one a "dash."—ED.

ceases, the bar is brought back against the right-hand screw by a spring, and the local battery circuit is broken.

There are different kinds of relays—that represented in Fig. 376 (*Froment's*) is the same as shown in Fig. 377.

The *Morse* receiver, as used on the French lines, has been modified by *Digney* so as to trace the signs in ink; this does not require so much force and leaves a more visible mark.

The *Morse-Digney* indicator or receiver is shown in Fig. 378. A train of clockwork drives rollers, which draw a strip or riband of

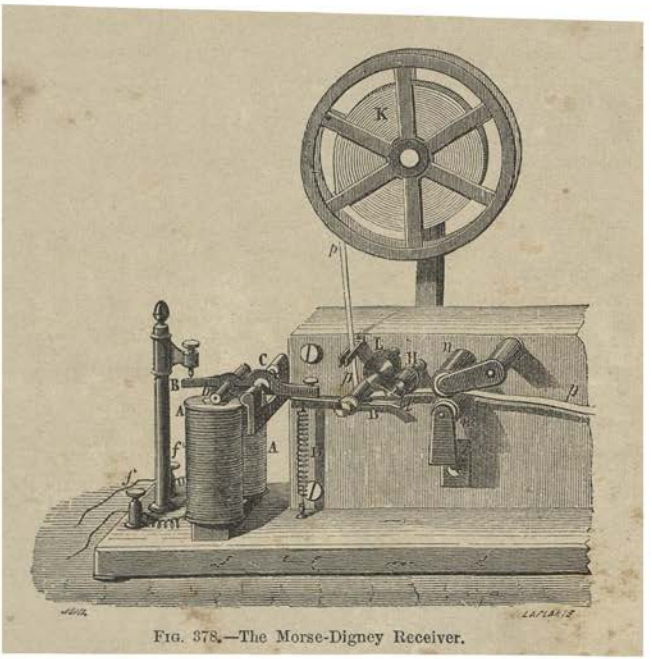

FIG. 378.—The Morse-Digney Receiver.

paper *ppp* off the long roll K. The same wheel-work turns the printing cylinder H against the ink-pad L. The armature B B′ on the lever is attracted by the electro-magnet when the current passes, and then the point L presses the paper against the printing cylinder, thus marking a line on it instead of a scratch in the paper itself by the ordinary Morse instrument. Digney's apparatus can work without a relay when the line is short. Relays are added in long lines or to work alarum bells. Fig. 379 represents the interior of a Morse-Digney instrument-room without relays. To the right is

seen the battery wire, *p*, the key with the galvanometer and the lightning conductor, with both of which the transmitter communicates. In the centre is the receiver and the driving clock-work, which is furnished with its winding-up key. To the left at the back is the alarum bell.

In England Morse *sounders* are now extensively used; also ink-writers differing slightly from the Digney form, being Johns's modification of the Morse embosser. The standard relay of the

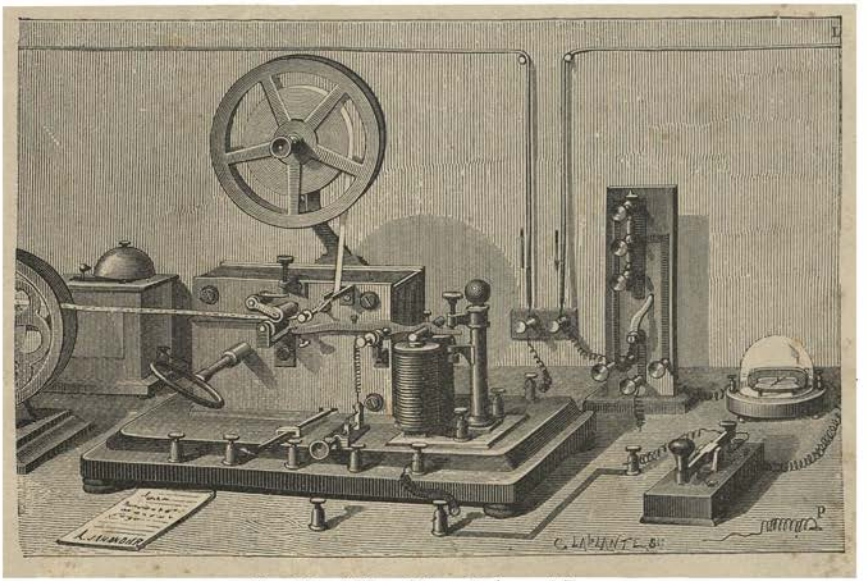

FIG. 379.—A Morse-Digney Instrument Room.

British Postal Telegraphs is an instrument far more sensitive than Froment's.

The Morse system is in common use both in this and other countries. By a convention which is now generally adopted the Morse code or alphabet of dots and dashes for letters, figures, &c., is as follows:—[1]

[1] The Morse Code given above is that adopted by the International Telegraph Service and by the Conference held in London on 28th July, 1879. A dash is equal in length to about three dots. A space about equal to a dash is left between two letters and about twice this length between two words; but in practice these must vary more or less with the operator.

MORSE ALPHABET.

(INTERNATIONAL MORSE.)

Letters.

e	▪	f	▪▪▬▪
t	▬	l	▪▬▪▪
i	▪▪	p	▪▬▬▪
a	▪▬	j	▪▬▬▬
n	▬▪	b	▬▪▪▪
m	▬▬	x	▬▪▪▬
s	▪▪▪	c	▬▪▬▪
u	▪▪▬	y	▬▪▬▬
r	▪▬▪	z	▬▬▪▪
w	▪▬▬	q	▬▬▪▬
d	▬▪▪	ä	▪▬▪▬
k	▬▪▬	ö	▬▬▬▪
g	▬▬▪	ü	▪▪▬▬
o	▬▬▬	ch	▬▬▬▬
h	▪▪▪▪	é	▪▪▬▪▪
v	▪▪▪▬		

Numbers.

1	▪▬▬▬▬	6	▬▪▪▪▪
2	▪▪▬▬▬	7	▬▬▪▪▪
3	▪▪▪▬▬	8	▬▬▬▪▪
4	▪▪▪▪▬	9	▬▬▬▬▪
5	▪▪▪▪▪	0	▬▬▬▬▬

Stops and Signs.

Period, or full-stop	▪▬▪▬▪▬	Hyphen	▬▪▪▪▪▬
		Dash	▬▬▬▬▬▬
Repeat, or interrogation	▪▪▬▬▪▪	Apostrophe	▪▬▬▬▬▪
		Parenthesis	▬▪▬▬▪▬

FIG. 380.—The Morse Code.

Fig. 381 is a facsimile of a message and its translation into the ordinary letters.

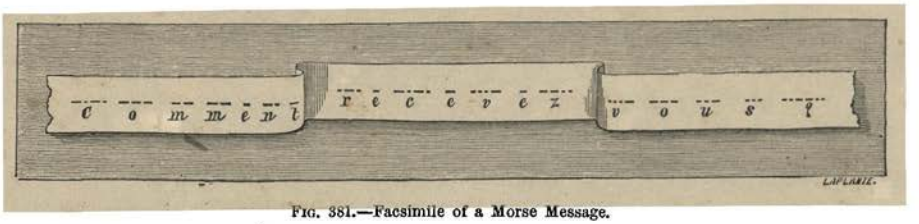

FIG. 381.—Facsimile of a Morse Message.

§ 2.—*Hughes's Printing Telegraph.*

The idea of printing the despatch is not new. In the early days of the electric telegraph (1841) Wheatstone took out a patent for printing the message in ordinary letters on a riband of paper. Since then many inventors have followed out the same idea, with more or less success. Amongst these are Vail, Bain, Brett, Du Moncel, Frietel, Theiler, Dujardin, Thomson, Digney, &c. But the most perfect of all these systems, for obtaining rapid transmission, is the printing telegraph of Prof. David E. Hughes. It is a more complicated and costly apparatus than the Morse, and more difficult to manage, requiring skilled and experienced operators, but offers in return the advantage of sending messages somewhat more rapidly than the Morse. In the Hughes system, for each letter or signal only one current is required to be sent instead of three or four as in the Morse.

There is also this arrangement, that when the sending apparatus is at work in the transmitting office, the receiver of this office works at the same time, and in the same manner as the receiver in the office to which the message is sent, consequently the message is printed at the same moment in both offices, thus giving a double control or check.

Plate X. gives a view of the complete apparatus. It is set in motion by powerful clock-work, with a driving weight of about one hundredweight. The sending key-board is composed of twenty-eight keys, twenty-six for letters, figures, and other signs marked on them, except one blank space for intervals between words, and another to

print, when desired, the sign, figure, or signal that is on every key above the letter.

The clock-work drives at different speeds three axes or shafts, two of which are horizontal, the other vertical. The first of these is called the *type-shaft* because it carries on its end a type-wheel T (Figs. 382 and 383) with the letters of the alphabet, engraved in relief on its circumference, whilst in the intervals are the figures, marks of punctuation, or other signals necessary in the composition of messages. Behind the type-wheel, and on the same axis is the *correcting wheel* T′, whose function is to maintain the synchronism of the movements of the two receivers simultaneously. Two other toothed wheels serve to transmit the motion to two other axes.

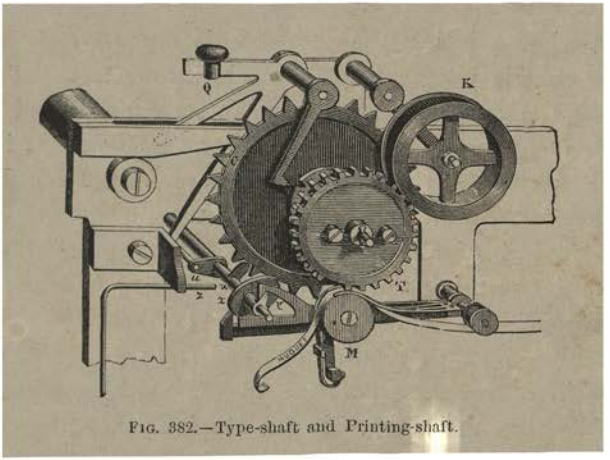

FIG. 382.—Type-shaft and Printing-shaft.

The second or *printing-shaft* turns much faster than the type-shaft. It carries four cams *u*, *w*, *x*, *y*, (Fig. 382), the functions of one being to press the printing roller M against the paper, and this against the letters of the type-wheel, which are inked by a pad K. The printing-shaft consists of two parts locked together by the ratchet-wheel and click or detent *ii* (Fig. 383) only when the current is passing, so that the part which prints the letters only works when the keys on the sending instrument are pressed down and the current transmitted.

The third shaft *a* (Pl. X.) is vertical, and has the same speed as the type-wheel which drives it by means of bevel wheels. In revolving it carries a horizontal arm with a contact-piece called a *chariot*,

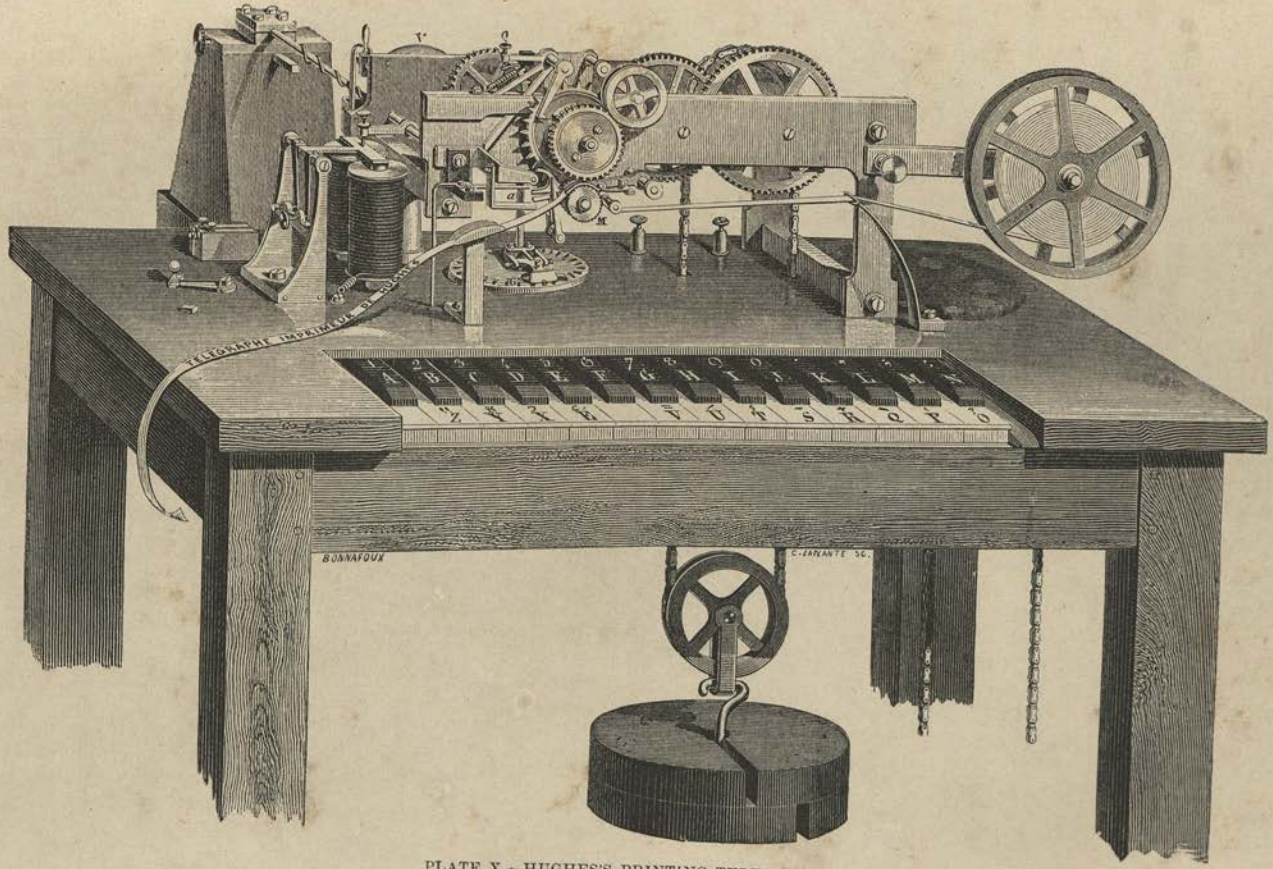

PLATE X.—HUGHES'S PRINTING TELEGRAPH.

over a horizontal disk G, so that this chariot makes one complete revolution during one turn of the type-wheel. The disk G is pierced with as many holes as there are keys on the key-board, or letters on the circumference of the type-wheel, so arranged that the contact-piece of the chariot passes over them. Fig. 383 shows a section of the apparatus through the type-shaft and the vertical shaft a carrying the chariot.

The vertical shaft is formed of two metallic parts insulated by an ivory cylinder, and the revolving arm on this shaft forming the chariot

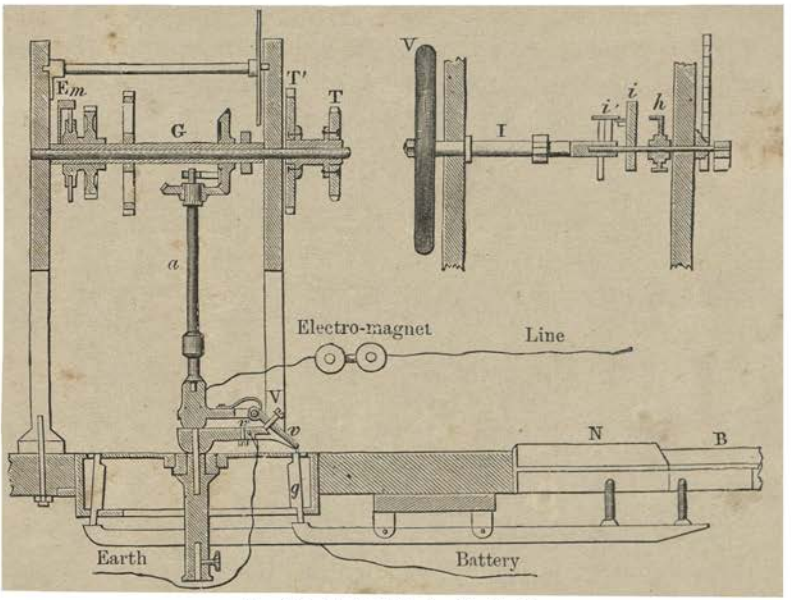

FIG. 383.—Vertical Shaft with Chariot.

is itself composed of two pieces v and v', joined by the screw V. The piece v when the shaft rotates passes exactly over the holes in the disk; and while it remains pressed down as in the figure, the current from the battery passes through v, the screw V, and the lower part of the shaft to earth (see also Fig. 384). But if a key B N on the key-board (Fig. 383) is pressed down its end raises a pin g, which lifts up the piece v of the chariot, and insulates the two parts of the shaft a; then the current coming from the battery along the circuit in the direction of the arrows t G B a (Fig. 384) passes through the coils of

the electro-magnet E, thence to the line-wire L′, and acts on the apparatus of the receiving office. Each time a key is pressed down a similar effect is produced; but as soon as the key rises the current is interrupted and the effect ceases.

The electro-magnet E (Fig. 384) consists of two soft-iron cores, round which the coils are wound, and is in contact with the poles of a permanent steel horse-shoe magnet A placed beneath it. When the current is not passing the armature and the lever p are attracted by the poles of the electro-magnet influenced by the permanent magnet, but as soon as the current passes, it acts in a direction contrary to the

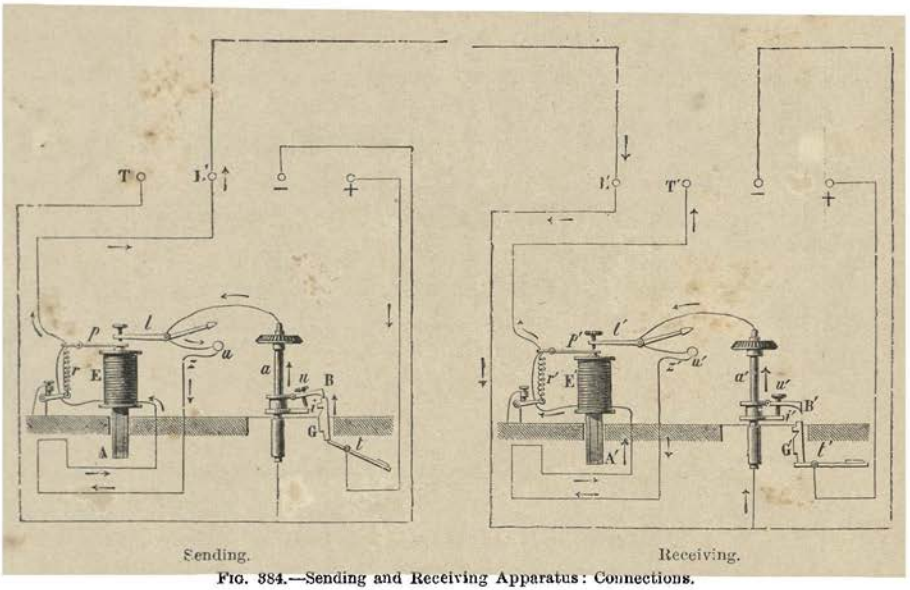

FIG. 384.—Sending and Receiving Apparatus: Connections.

permanent magnet, partially reversing the magnetism of the soft iron cores, so as to enable the opposing spring r to overcome the induced magnetism, and pull the lever p up off the cores. The armature thus raises another lever l which acts by means of the ratchet-wheel and click locking together the two parts of the cam-shaft which is set in motion; then, after one turn, the click ii becomes disengaged, and one part of the shaft is left at rest. The part of the printing-shaft O, which is thus turned every time a current passes, carries a pointed tooth p (Fig. 385) which comes against the tooth b and suddenly raises the lever a b, about an axis at T, thus making the printing

roll M (Fig. 382) press the strip of paper against the inked letter of the type-wheel, which is just passing. Now the letter printed at each passage of the current corresponds to the one on the key which has been pressed down, raising the pin *g* through the hole in the disk G against the contact-piece *v* of the chariot passing over it. The letter is thus printed flying, so to speak, since the type-wheel does not stop. One of the other three cams of the printing shaft lowers the lever J U with a spring and click *r*, turns the rock wheel E one tooth, and thus advances the strip of paper through the distance for one letter; the third cam gears into the teeth of the correcting-wheel T′, so as to keep the receiving instruments from losing or gaining on the sending instrument by maintaining perfect agreement between the type-wheels

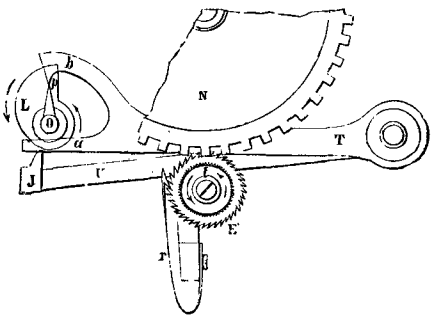

FIG. 385.—Mechanism for Printing.

and the chariot; a fourth cam serves to adjust the apparatus to the blank space on the type-wheel before the message is sent, so that the sending and receiving instruments are alike to start with. We will now describe the method of sending a message:—

The operator at the sending office, in order to communicate with any office on the line, raises the brake off the fly-wheel of the clockwork, which at once starts; then he presses a blank key, which rings the bell in the receiving office. Being thus warned the receiving clerk sets his apparatus going, and simultaneously the two operators, pressing on the pedal Q, regulate their apparatus by putting the type-wheels to the blank space; then they find out whether they are together by repeating a certain number of times the same letter, A for example. If they agree in speed, this letter is repeated at the same time, if not it is

the preceding or the following letter which succeeds the A, and marks its delay or advance. The regulation is effected by adjusting the regulator with a conical pendulum, or a vibrating plate.

The apparatus being regulated, the transmitting office sends successively, by pressing the keys of the piano-like keyboard, the letters composing the message, this is printed simultaneously in the two offices, and the strip of paper, cut in pieces of equal length, and pasted on a sheet, is thus delivered to the public.

It may be seen by this description that the Hughes printing telegraph is decidedly more complicated than the systems already described. But this complication, necessitated by all the difficulties of the problem, only renders the result obtained more admirable, when you think that the transmission is two or three times more rapid than that by the Morse method. Whilst with the latter you obtain on an average twenty, or twenty-five despatches of twenty words in an hour, Hughes's telegraph permits of from fifty-five to sixty being printed in the same time. It is extensively used on the Continent.

[*Note.*—A much greater rapidity is reached in England and in the United States with Morse sounders, and even with Morse ink-writers than that mentioned above —ED.]

§ 3.—*Autographic Telegraph.—The systems of Caselli, Meyer, Edison.*

We have seen that the idea of utilizing the electrolytic properties of the current to transmit signals dates from the early part of this century. These first attempts are associated with the names of Coxe, Sœmmering, and Schweigger. Signals were indicated by bubbles of hydrogen in Sœmmering's telegraph. In 1839, E. Davy made use of electro-chemical reactions to print signals on a sheet of paper or material specially prepared. Twelve years later Bain constructed a writing telegraph, based on the power of the voltaic current to decompose cyanide of potassium, producing Prussian blue on the receiving paper during the passage of the current. The sending and receiving apparatus being identical with those of the Morse telegraph. Bain obtained blue dots or dashes as signals on the strip of paper. At first Bain made the metal point of the receiver trace a spiral on ordinary paper, but the principle was the same.

An *autographic telegraph* or *pantelegraph* gives at the receiving

station a faithful reproduction, in fact a facsimile of the original despatch, even of drawings, cards, plans, portraits. It is really an autograph received from the sender, so as to have when necessary an authentic document.

Suppose there are arranged, in the sending and receiving stations, two copper plates M, R (Fig. 386), connected by T to earth. On plate M in the sending station there is placed a sheet of metallized paper with the despatch written on it by the sender in thick insulating ink. At the receiving station, a sheet of paper impregnated with potassium ferrocyanide is placed on the plate R. Two iron styles, s, s', in circuit with the battery and line-wire, can mark simultaneously and at the same rate, very close parallel lines on the two sheets of paper. These styles are driven and regulated by pendulums that oscillate with synchronism in the two stations. Another movement adjusts the papers, as the parallel lines are traced, so that

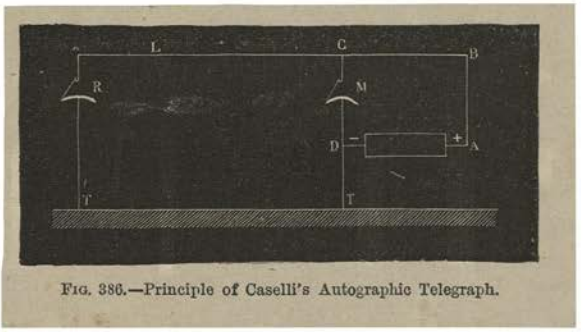

FIG. 386.—Principle of Caselli's Autographic Telegraph.

if the style s has been over the whole surface of the paper on the sending plate where the despatch is written, the style s' will have been over an equal surface of the chemical paper on the receiving plate. When the style s is on the metal or conducting part of the paper, the current from the battery follows the circuit A B C D, which has much less resistance than the line-wire; thus the current flows to earth at the sending station and the receiving apparatus is not influenced at all.

On the other hand, the style of the sending apparatus by touching the insulating parts, that is the ink of the written despatch or drawing breaks the circuit A B C D, making that of the line, and a current is sent to the point s' of the receiver. Under the influence of this current the part of the sheet covered with cyanide, where the current passes to go to earth, is decomposed, producing a mark of Prussian

blue on the paper. This impression is reproduced every time the point of the manipulator meets the parts marked with the insulating ink; and the number and lengths of the lines gone over simultaneously by the two points will be identical at the receiving and sending stations. The despatch is exactly reproduced on the cyanide paper in blue lines; the only difference from the original, being that the successive lines made by the points not being absolutely in contact, the traces of the reproduced despatch will not be rigorously unbroken lines. This difference is shown to the right in Fig 387, which is a reproduction of the design to the left.

As the Caselli telegraph can thus be used to copy all sorts of drawings and designs traced on the metallized paper, the name *pantelegraph* has been given to the apparatus. In Fig. 388 a pendulum,

FIG. 387.—Facsimile of Design reproduced by Caselli's Pantelegraph.

with metal stem two metres long, is suspended from a solid metal frame; the bob is a rectangular mass of soft iron about eighteen pounds in weight, which vibrates between two electro-magnets. Two arms half-way down the stem communicate the oscillatory movement of the pendulum, on one side to the sending apparatus, and on the other to the receiver. As these two work separately, one of the arms is detached, when the other is moved. This arm determines the movement of the style on the surface of the transmitter, where the despatch is placed. The arm is joined to a lever which carries the style. In its successive oscillations, it describes, with the lever and tracing style a series of parallel arcs, on the surface of the cylindrical sheet of metal, on which is placed the metallized paper of the despatch. When the pendulum swings in one direction the style moves from left to right across the despatch. Then the slider strikes a pro-

jection, and raises the style from the paper during the return swing. This apparatus only works during half a complete swing of the pendulum. Experience has shown that there is not identity in the effects

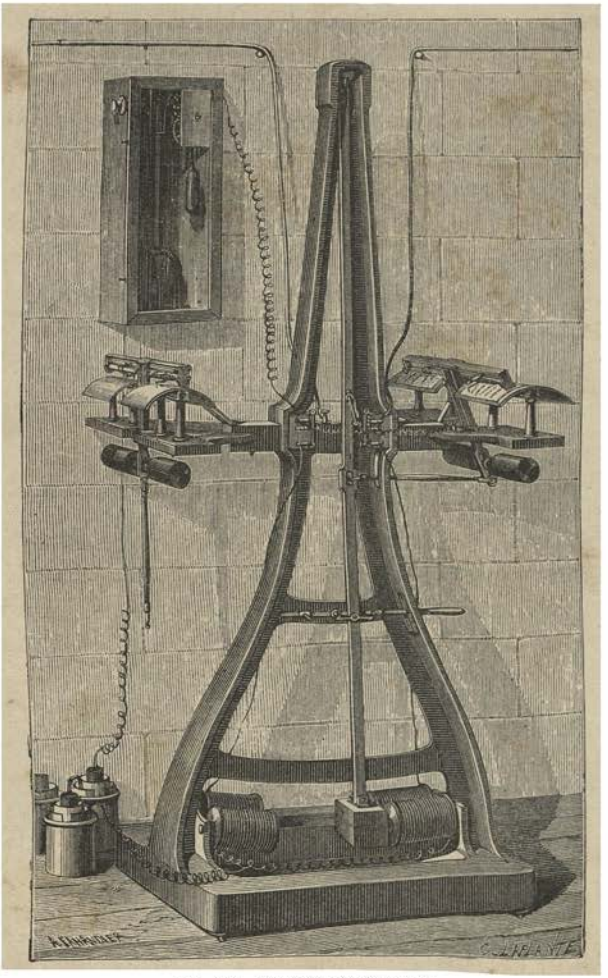

FIG. 388.—Caselli's Pantelegraph.

produced by the swings in the opposite directions; but to utilize these the sending and receiving apparatus are made double, with the mechanism reversed. Thus no time is lost, and one despatch can be sent whilst another is being received. An essential condition for the

proper working of the Caselli pantelegraph is that there should be perfect synchronism between the pendulums at the two stations. Not only must the swings be made at the same time, but the amplitude of their vibrations should be exactly equal, so that the tracing points may move simultaneously and at the same rate at both stations.

The clock-pendulum seen on the top left-hand corner (Fig. 388) makes and breaks the local battery circuit round one or other of the electro-magnets, between which the large pendulum bob of soft iron moves. This is attracted by one or other of the electro-magnets according to the position of the clock-pendulum which thus com-

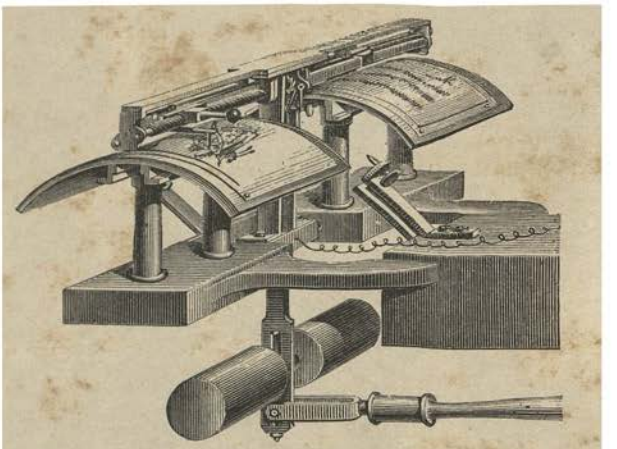

FIG. 389.—Sender and Receiver of the Caselli Pantelegraph.

pletely controls the pantelegraph. The commutator, whose function is to open and close the circuit, is moved by an articulated piece which rubs hard on the stem of the pendulum. Thus the regulation of the two pendulums at the sending and receiving stations is dependent on the synchronism of the chronometer pendulums which accompany them. These regulating chronometers, whose pendulums move at double the rate of the pantelegraph pendulums, are themselves regulated independently with great exactness.

The cyanide paper on which the despatches are printed needs to be carefully prepared and kept damp. The quality of the paper itself is important. The metallized sheets used with a peculiar ink, are made of white paper carefully silvered in pressing, with large

margins. They have three lines; one serves as a guide for the style at starting, the two others mark the limits of the despatch.

The working of the pantelegraph is very simple. The written despatch is placed on the surface of the sending cylinder. The operator in the office sends the call signals and then sets the pendulum swinging. The despatch is transmitted automatically without any manipulation, and consequently without any special knowledge being required. As it is possible to send two despatches at the same time, abbreviations may be used to increase the rapidity of transmission.

The long pendulums in Caselli's telegraph usually make forty oscillations per minute, and the styles trace forty lines about one third of a millimetre apart. In one minute the lines gone over by the styles cover thirteen millimetres, and in twenty minutes 260 millimetres. As the lines are eleven centimetres long it follows that in twenty minutes Caselli's apparatus furnishes the facsimile of writing, portraits, or drawings traced on a metallized sheet of paper eleven centimetres in width and twenty-six centimetres long. To ensure clearness of reproduction the first writing should be very legible and in large characters.

In 1865 the line from Paris to Lyons and Marseilles was opened to the public for the transmission of despatches by this system, which has been abandoned owing to the despatches being often illegible.

Meyer, an engineer in the French telegraph service, designed and constructed an autographic telegraph, which works with wonderful regularity and rapidity in reproducing the facsimile of transmitted despatches. The transmitter of Meyer's autographic telegraph (Fig. 390) is a metal cylinder, around which the written despatch is rolled as in Caselli's system.

This cylinder is driven by clock-work regulated by a vibrating plate. A metal style carried by a little railway moves in the same direction as the cylinder, on the surface of which it describes a helix or spiral with convolutions very close together. It is connected with the battery and line-wire, and thus makes or breaks the circuit between the two stations according as it rests on conducting or insulating parts of the metallized paper, that is, as it touches the layer of silver on the paper, or the insulating ink of the despatch.

So far, except the difference in the motion, the principle of transmission is the same as in the pantelegraph already described.

The receiving apparatus is composed of a cylinder worked by rotatory motion identical with that of the transmitting cylinder. Both turn together at the same uniform speed. On the surface of the receiving cylinder there is wound throughout its entire length a pro-

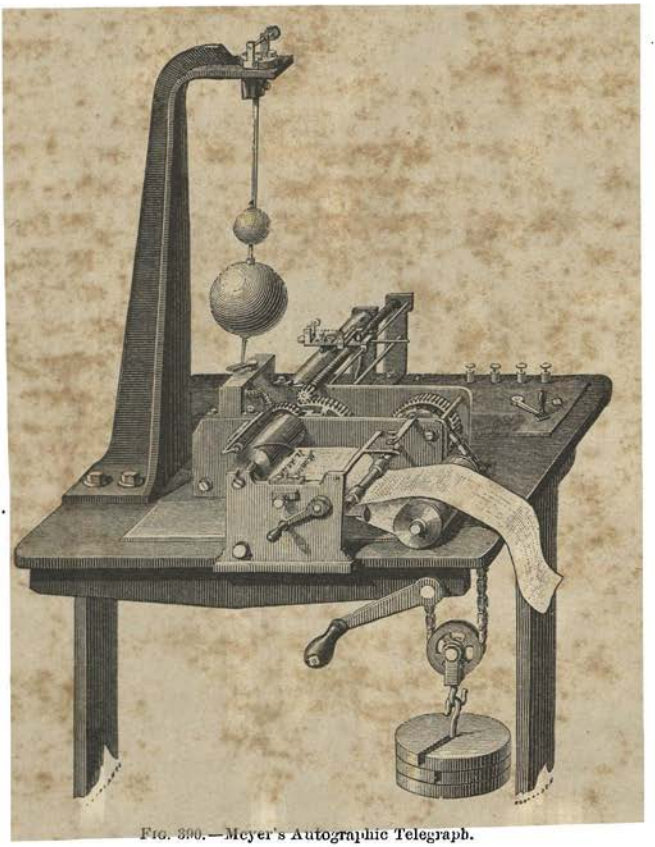

FIG. 390.—Meyer's Autographic Telegraph.

jecting helix or coil exactly equal in length to the circumference of the transmitting cylinder. Now imagine a sheet of paper arranged parallel to the lower mover of the receiving cylinder at a little distance below. As the apparatus works every time that the current is sent into the line, that is, when the style of the sender comes on the insulating ink of the despatch, the paper is raised

by a pallet and pressed against the point of the projecting helix, which at that moment is on the lower driver. During a complete turn, described simultaneously by the sender and receiver, this contact is made and broken as often as the style is on or off the inked lines of the despatch. Now, the projecting helix being covered with thick ink by a roller, there is obtained, on a straight line, occupying the width of the paper, a series of points or black marks, the exact reproduction of the lines met by the style in one turn of the despatch. As the paper is moved under the cylinder, advancing in each turn an amount equal to the intervals between the spirals of the style, there will be on the receiving-sheet a succession of marks forming the facsimile of the despatch.

Meyer's, like Caselli's telegraph requires perfect synchronism in the apparatus at the sending and receiving stations. Thus it is necessary to regulate the clock-work that serves as the driver. If Caselli's apparatus be a combination of Bain's electro-chemical telegraph with special mechanism, synchronism being regulated by electricity, Meyer's apparatus may be considered as a combination of Caselli's telegraph with parts of the systems of Morse and Hughes.

The autographic telegraphs of Meyer and Caselli figured at the Electrical Exhibition in 1881. A third system due to *Lenoir* was also shown there. In Lenoir's apparatus the despatch is written with insulating ink on metallized paper. At the receiving office the impression is made by means of a capillary tube of iridium filled with glycerine ink. When the tracing point or style of the sending apparatus touches the insulated part, that is on a mark of the despatch, the armature of an electro-magnet at the receiving station presses the point of the tube on the paper and prints a mark like that on the despatch. Thanks to the synchronism of the sending and receiving apparatus, all the lines thus traced reproduce a facsimile of the despatch.

Edison has his sending and receiving apparatus identical. It is driven by an electric motor, regulated by a conical pendulum; this motor turns a cylinder at each office simultaneously; the written despatch is rolled on the cylinder in the sending station, and on the other the paper intended to receive it. The despatch to be sent is traced on tough paper, not with thick insulating ink, but with the point of an ordinary lead pencil, rather hard. The lines

written in this way produce hollows in the paper. Now the rotation of the sending cylinder gives a spiral motion to a narrow plate on its surface, pierced with a hole at its end, and in this hole is fixed a movable steel point which rests on the paper of the despatch. Whilst it only touches the smooth parts of the paper, the point remains on a level with the plate; but if it comes to a hollow, that is on the written part, the point descends or sinks into it. By means of a suitable contact a current is then sent into the line. The style on the receiving cylinder, acted on by the current, produces at the same instant a blue line on the paper every time that the sending point sinks into the hollows of the despatch. All the lines thus obtained constitute an autographic reproduction of the written despatch.

Such apparatus is of more historic than really practical importance on account of the few cases in which any one requires to send the autograph of their writing.

Other *Writing Telegraphs* have been designed by Mr. E. A. Cowper, of London, and by Mr. J. Robertson, of New York. In both of these instruments the operator writes upon a moving strip of paper, and in the act of doing so produces automatically corresponding changes of resistance in two transmitting circuits. These transmitting circuits are connected at the distant end to two electromagnets the armatures of which are geared to a writing pen that rests on a second ribbon of paper, which is drawn beneath it by clock-work. The pen writes marks very closely resembling those made at the sending station, though scarcely autographic.

The latest writing telegraph is that of Mr. O'Brien of Liverpool, who employs a step-by-step means of transmission and reception, so that the paper at both ends lies stationary. Mr. Elisha Gray made a similar instrument about the same time.

CHAPTER V.

TELEGRAPHIC APPARATUS FOR RAPID TRANSMISSION.

§ 1.—*Automatic Transmission.—Wheatstone's Automatic Transmitter.*

DURING the last thirty years telegraphic correspondence has been so extended, particularly on lines in the immediate vicinity of great centres of population, that the most perfect systems as regards simplicity of signals and rapidity of transmission have proved inadequate. The skill of the best telegraphists has not been able to supply this want, and in many places on certain days the offices have been encumbered with delayed despatches, whilst the continual lowering of the charge for messages has only increased the inconvenience of the situation.

How can the speed of transmission be increased ?

The idea which seemed at first most natural and simple was to multiply the number of the wires on the most encumbered lines, and to increase in proportion the number of persons employed in the transmission and reception of despatches. This solution would apply on lines not very much used in the interior of great cities, and it is the most economical under these conditions. But it is impracticable on long lines because then the first cost of installation would become very high. It was necessary to look further for the solution of the problem, to design methods for increasing the capacity of transmission of one wire or its telegraphic delivery. This has been done in different ways, and generally the systems for rapid transmission may be classed in three groups.

In the first—*automatic transmitters*—despatches are signalled continuously in series without requiring the work of a special clerk.

The second class comprises apparatus in which special arrangements of ordinary systems permit of sending many despatches at

once on the same wire, in the same direction or in two opposite directions; this is the *simultaneous transmission* system.

The third class includes apparatus in which the same wire can be utilized by several senders making use of the line currents in turn and for very short periods; these are *multiplex transmitters.*

A skilled operator using the Morse key can scarcely send, on an average, more than 500 words[1] per hour, that is, twenty-five despatches of twenty words, each of five letters. However, the wire could transmit a much larger number of signals. Automatic transmitters supply this want by maintaining the maximum speed of signalling without increasing the fatigue of the operator. As an example of the automatic transmitter we shall take *Wheatstone's Transmitter*, sometimes called the *Electric Jacquard*, from the resem-

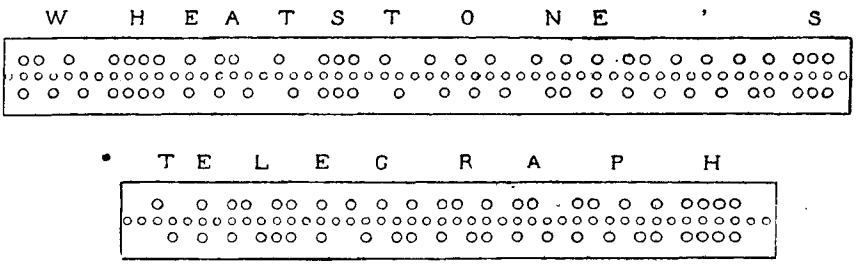

FIG. 391.—Perforated Strips of the Wheatstone Automatic Service.

blance between this apparatus and the mechanism of the Jacquard loom. The despatches are prepared beforehand. This is done by punching strips of paper with holes, the arrangement and spacing of the holes corresponding to the dots, dashes, and intervals necessary to make a despatch in the Morse alphabet. Fig. 391 gives an example of this *perforation.* In the middle of the strip there is a row of equi-distant holes, to ensure uniform unrolling of the paper on the *transmitter* on which a rack, driven by the clock-work of the transmitter, works in the central perforations and moves the paper forward.

The other two rows of holes form the dots and dashes of the Morse signals, two holes in a straight line or directly opposite each other form a dot, two holes in a diagonal direction indicate a dash.

[1] As already explained (p. 616) this speed is exceeded in England and in the United States, where an expert signaller will often transmit more than thirty words per minute.—ED.

A single hole in the central row corresponds to an interval between two letters, three holes to that between two words. Thus it is obvious that the portion of the perforated strip Fig. 391 should be translated on the strip in the printing receiver by the signals shown in Fig. 392.

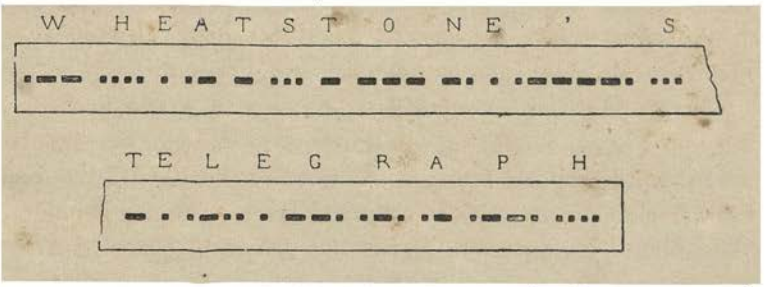

FIG. 392.—Despatch printed Automatically at Receiving Office.

WHEATSTONE'S AUTOMATIC TELEGRAPH.

The *Wheatstone perforator* represented (Fig. 393) in plan and elevation is used to prepare or punch the paper ribbons. Three buttons

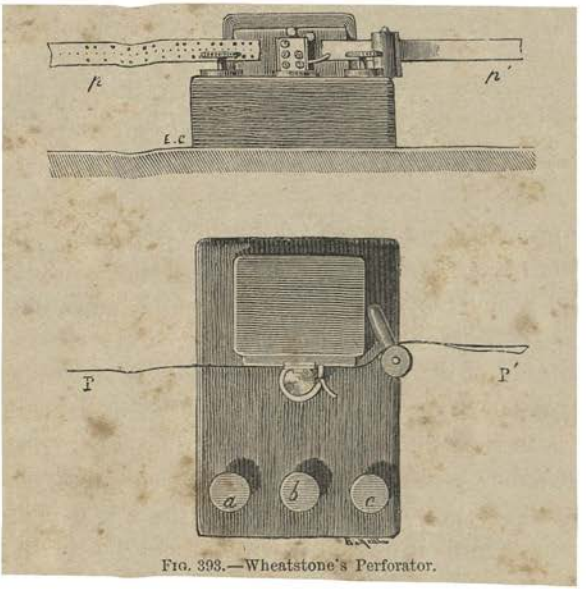

FIG. 393.—Wheatstone's Perforator.

a b c correspond to three levers, one producing the holes marking a *dot*, the other indicating *dashes* and the middle one *b* the holes

in the middle line. Pushing down a steel point against the moving strip of paper $p\,p'$ forms the holes which are spaced and arranged as above described. The messages may be written separately by specialists without making use of the line-wire. The result is the time necessary in preparation does not interfere with that for the transmission, this being done automatically and continuously, with much greater speed than by the most skilful operator.

The *transmitter* represented in diagram, Fig. 394, enables us to see how the punched strips can transmit to the wire the signals that are inscribed on itself beforehand. R is an ebonite rocking beam of lozenge shape driven by wheel-work, its oscillations being regular and uniform, corresponding to the advance of the punched strip from

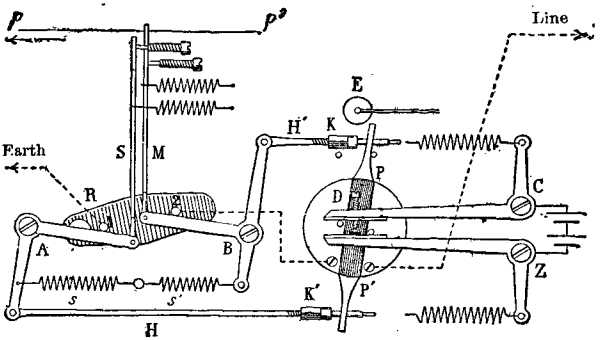

FIG. 394.—Wheatstone's Automatic Telegraph. Diagram of Transmitter.

one hole to another along the central line. Two metallic pins, 1 and 2, fixed in this rocker, press alternately against the arms of the metal levers A and B and communicate to them a reciprocating motion in perfect unison with that of R. Two stems, M and S, fixed at the ends of the same arms of the levers, oscillate vertically underneath the two perforated rows of the strip $p\,p'$ corresponding with the signals of the despatch; if, in their movement up and down, these stems meet one of the holes they pass through the strip and a current is sent through the line; on the other hand, if there is a plain interval, they are stopped in their upward movement and the circuit is broken. In short, by the movement of the two rods H and H′ and the two rings K and K′ at their ends, the arms of the levers A and B move a disk D, having two metal segments insulated by a central band. This

disk oscillates round its centre like the rocking beam R, whilst two levers C and Z connected with the poles of the battery, press alternately against the two pins fixed on each half of the disk. A small screw passing through the upper lever C presses against a piece of ebonite on the lower lever Z and prevents the battery from being short-circuited. Fig. 395 shows the successive positions occupied by the disk at each half of one complete oscillation. It is easy to see that in its first position a positive current is passed through the line, and in the second position a negative current. These alternate currents would succeed each other without interruption if the perforated strip pp' were not in its

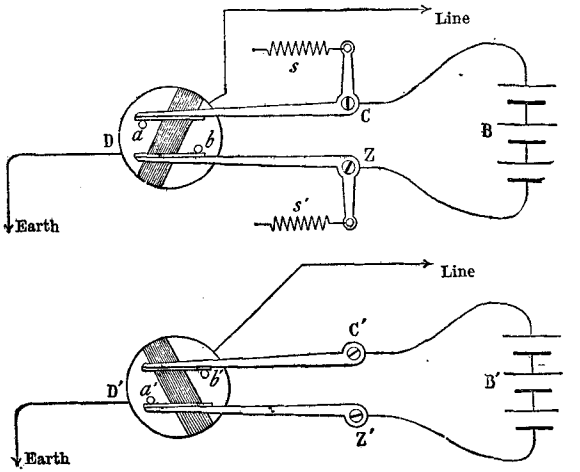

FIG. 395.—Transmission of Signals.

place, because then the stems S and M would not be limited in their upward motion, and by the pins 1, 2, *a* and *b*, the circuit would be maintained unbroken. This is what does happen so long as the stems, meeting the holes, can pass through the strip.

On the other hand, at the parts of the strip not perforated, the play of the stems being limited, the levers do not reach the terminals 1 and 2. In this case the communication with earth or with the line is broken, and no current passes. Thus at each oscillation a *dot* of the despatch gives a reversed current; but for a *dash* two oscillations occur before reversal.

The *receiver* (Fig. 396) is simply a Morse ink-writer or printer.

The paper on which the signals of the despatch are to be inscribed is opposite the inking cylinder; and an impression is produced when

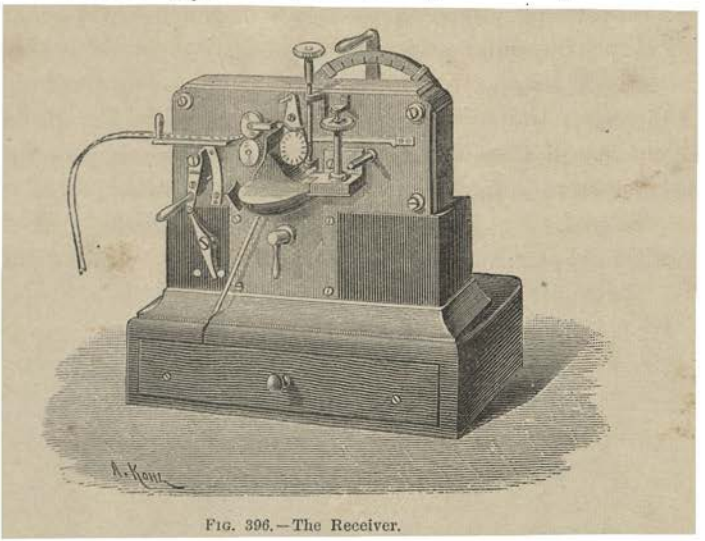

FIG. 396.—The Receiver.

the printing arm presses the paper against the cylinder. The motion which produces this pressure is given by the axle *a*, Fig. 397, moved

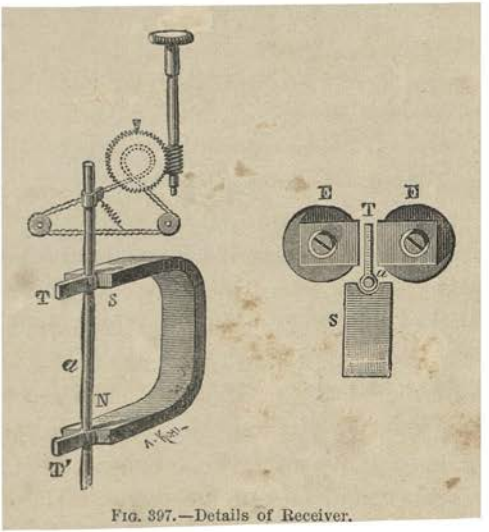

FIG. 397.—Details of Receiver.

by the tongues or armatures T and T′, of soft iron at the poles of the permanent magnet N S. These armatures, thus polarized, are attracted

between the arms of an electro-magnet E F, which are acted on by the line currents.

When the current passes the armatures are attracted, and they return to their normal position when a reverse current is sent through the electro-magnet coils. This effect is produced instantaneously when the signal transmitted is a dot, since, as we have seen, the dot is given by a momentary current, followed immediately by a very short opposite current. Then the contact of the printing arm with the strip of paper is of very short duration, and it is a dot which is traced.

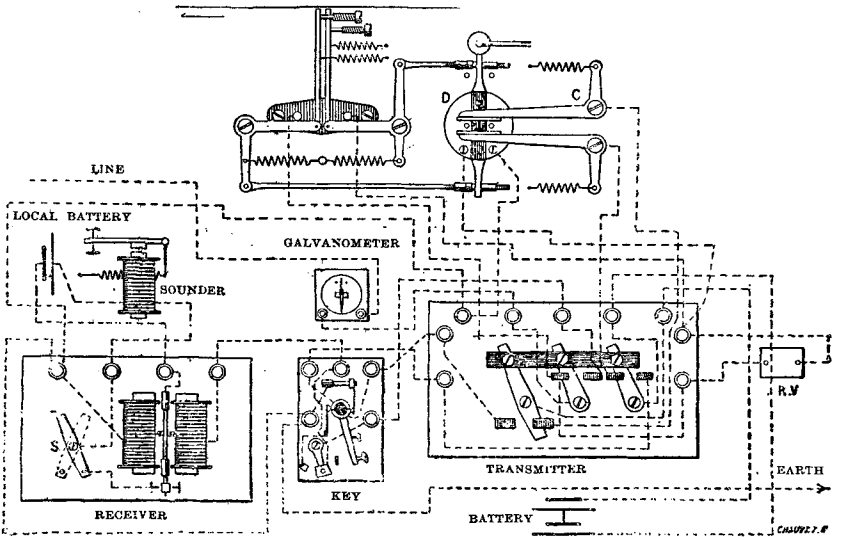

FIG. 398.—Plan of a Station on Wheatstone's Automatic System.

If the signal which follows is to be a *dash* there is a current of short duration, but it is not followed by an opposite current till after a longer interval. The contact of the arm with the strip is longer, and the trace printed is a line or dash.

Fig. 398 shows the connections and arrangement of apparatus for sending automatically. The Sounder is in the local battery circuit with the receiver.

The despatches on the perforated strip pass to the machine which sends them by the wire. Thus on a circuit 500 kilometres in length, 12 despatches of 30 words each are connected on a continuous band, and sent by the transmitter at once, and *vice versâ*. The wire from

London to Birmingham, for example, can send four distinct groups each of 12 despatches, and receive three similar groups in an hour. That is equal to 84 despatches of 30 words each; on an average of 5 letters per word making a total of 12,600 letters, or 210 letters per minute. It would come to 42 words a minute including all call signals and customary formalities.

An equal speed can be maintained in ordinary fine weather, and only requires five men at the receiving and sending stations, that is, two to connect the despatches on the paper strips, two to write and transmit, and a fifth to manage the apparatus, to look after the receptions, and ask for repetitions, &c. If they are parliamentary despatches, or for the Press, they are sent much more rapidly, because there is no necessity to group the despatches, and also because these transmissions generally take place only in one direction, either received or sent; these circumstances considerably reduce the initial delay of transmission. On the line from Aberdeen to London, 40 words a minute can be sent; from London to Edinburgh 50; between Newcastle-upon-Tyne and London 60; between Glasgow and Liverpool up to 120.[1] The speed is inversely as the length of the line.[2]

At present we may look forward to the adoption of an automatic transmission apparatus like Wheatstone's with previously perforated strips for transmission of despatches, as is used between Boston and New York on a line of 250 miles. The improvements made on the system by the inventors, Messrs. Foote, Romdal and Anderson, are such, that the speed of transmission attained is 1,000 or 1,200 words *per minute*. According to *Nature*, one wire alone, with fifteen perforators, fifteen copyists, and two good clerks at each end for sending and receiving, permits of there being prepared, transmitted and distributed 1,200 telegrams per hour—a number never before attained *with a single wire*.[3]

[1] These speeds have been recently very much increased, and with good conditions 250 words per minute can now be sent.—ED.

[2] "Automatic apparatus is used on almost all the great European lines. It is evident that the principal advantage of an automatic system consists not only in its great exactness, but in the increase of speed that is obtained in working it. It may be said that it doubles the capacity of the lines. . . . But the Wheatstone necessitates additional working expenses. When it works for several consecutive hours it requires two perforators, an adjuster, and three writers at each end."—TERNANT, *Les Télégraphes*.

[3] The American Company which uses this apparatus has designed a means of increasing the delivery on the line, which is only possible where the electric

§ 2.—*Simultaneous Transmission.—Duplex and Quadruplex Telegraphy.*

A second solution of the problem to increase the delivery of messages by a telegraphic line is that which consists of sending at the same time two messages through one wire, either in the same or opposite direction. In the *duplex* system the *simultaneous transmission* of two messages takes place in opposite directions between two stations at the same time. The *diplex* system consists in sending two messages through one wire at the same time and in the same direction. The *quadruplex* method is the combination of the *duplex* and the *diplex*, so that the one wire serves for the simultaneous transmission of four messages, two in each direction.

The first attempt at the solution of this problem by Dr. Gintl of Vienna dates from 1853; but the application of it did not become possible till much later. Stearn's duplex system was the first worked on the line between New York and Buffalo; in France it was applied on the line from Paris to Havre, with Hughes's apparatus; but it may be used indifferently, like all duplex systems, on any telegraphic apparatus whatever. Since then a great many similar systems have been invented, it is only important to know the general principle of their working.

Suppose (Fig. 399) two stations on the Morse system connected by one line wire L L'. The apparatus consists of manipulators or keys *a*, *a'* connected to the batteries P and P', and to the receivers or relays R and R'. The armatures of these receivers are opposite the poles of the electro-magnets A B and A' B'; but the coils are wound so that if two currents of equal strength transverse them at the same time no effect is produced on the poles.[1] Thus the magnetization

telegraph is a private enterprise. It supplies to its clients perforators, which enable them to prepare their despatches with perforated strips. Besides, instead of copying and transmitting in ordinary letters, the despatches received in Morse's signals, these very strips are sent to those for whom they are destined. The Company thus economizes time and men. The messages are charged for according to their length, so much by *the yard*, without counting the words.

[1] Instead of two insulated bobbins working in opposite directions, one bobbin may be employed; in that case the bobbin is formed of two separate but similar

that the currents tend to produce in the soft iron core of the electro-magnet, being at the same time in two opposite directions, is neutralized and no action is produced on the armature of the receiver.

Now what occurs when the current is sent from only one of the two stations, the left one for example? When the key *a* at this station is depressed a current is sent from the battery P, and divides at O. One part passes through the coil A into the line wire; the other goes into coil B, and thence to earth, so that the armature or receiver R is in no way affected. Why is it that these two branches of the transmitted current are thus neutralized? Evidently because

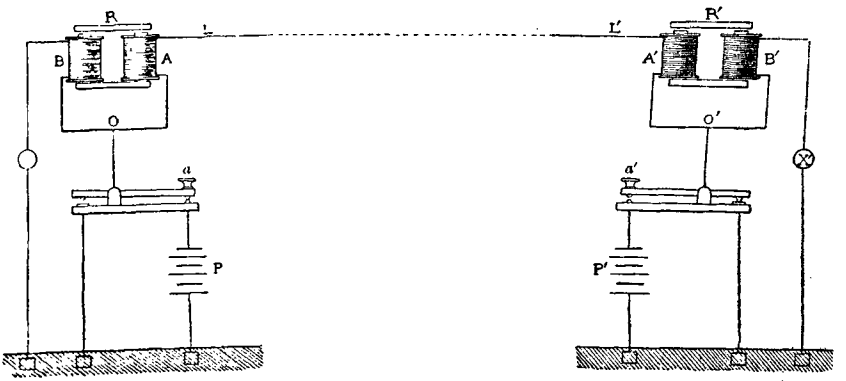

FIG. 399.—Principle of the Duplex System.

they are of equal *strength*, and consequently the circuits are equal, or offer an equal resistance to the current. To obtain this result the circuit of the coil B must be increased by putting in an artificial resistance, as a rheostat or resistance box X, equal to that of the line. By this artifice, which is the essential part of every duplex system, the receiver at the signalling station does not work, but remains free to record signals from the other station. The current passing through the line wire to the other station traverses the coil A' and goes through O' to earth. Another portion of the current dividing in O'

coils, wound round a soft iron core. The direction of the winding being the same, the currents have no effect on the core when they are equal and in opposite directions; but they have double effect when in the same direction.

passes into the coil B′ in the same direction as the first, so that the soft iron core is magnetized, and the armature R′ of the receiver attracted, and gives the signal.

The arrangement described is such that the signals transmitted from one of the stations does not act on the receiver of that station, but only on the other. Now let us see what happens when the two stations are sending at the same time, then let both the keys a, a', be depressed at the same time. Two currents coming from the two batteries, perfectly equal in their electromotive force, are sent into the line wire, where they neutralize or counterbalance each other, since they are equal, and in opposite directions. But then the portions of each current which, after branching at O and O′, go to earth by the coils B and B′, and through the resistance boxes X and X′, act directly on the receivers; the armatures are moved and the signals received at both stations. Thus in single transmission the receiver at the sending station does not work, but that at the other station receives the signals as usual. If the transmission is simultaneous, each receiver records the signal from the opposite station by the differential action of the two portions of the current which it sends, one of them being neutralized by the current sent into the line at the other station.

Duplex systems are now very numerous, there being a great variety of combinations based on the same principle. The two methods of duplex-working are: (1) The *differential method* above described; and (2) the *Bridge Method* which depends upon the principle of the *Wheatstone Bridge.*

We will describe, according to Du Moncel,[1] the Tommasi duplex system that figured at *The International Electrical Exhibition* of 1881; and which was tried between Mantes and Paris, on one of the lines of the Western Railway.

In this system at each station two batteries are employed, one having double the strength of the other, and in the circuit is placed an additional resistance, double that of the electro-magnet of the corresponding receiver. The key has a peculiar construction which enables it to combine or divide the current. Its end is furnished with an insulated handle c, c' with a contact screw, which oscillates between

[1] See *La Lumière Electrique*, September 17th, 1881, from which we have taken the description and illustration of the Tommasi duplex system.

two springs r, s, r', s', and acts as the current interrupter at a, a'. (Fig. 400.) As is seen by the figure, the electro-magnets of the receivers are connected to the line wire, and to the insulated handles c, c' of the two keys. The keys themselves are connected with the line by leads with the resistances R, R', double that of the corresponding electro-magnets. The batteries Pp and P'p' being connected with the apparatus, as in the Figure, in an opposite direction from one station to the other, this is what takes place when they are in use: Before either of the keys is depressed, the line and the electro-magnets E,E' are joined to earth by the handles c, c', and the springs s, s' which communicate with the earth plate; thus no battery is in circuit.

If the station to the left sends by depressing the key a, the

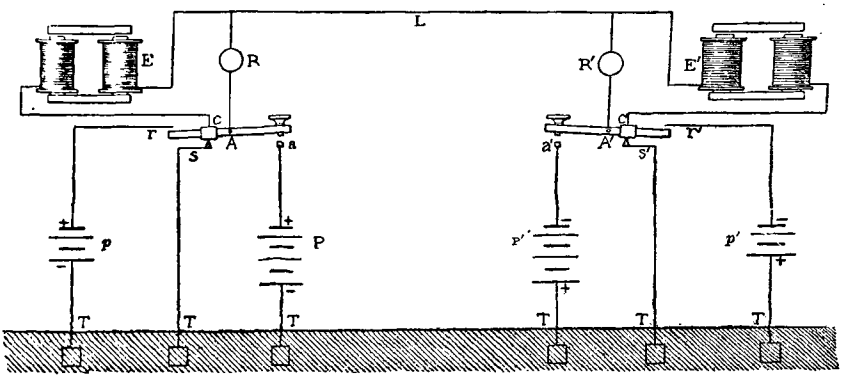

FIG. 400.—Tommasi's Duplex System.

battery P is put in communication with the line by the lead R; at its junction with the line wire L, the current branches into two, one to the right through the line, the other to the left through the electro-magnet E; but here the circuit on this latter side is broken, for on one side the spring s is no longer in contact with the handle c, and the way which might be open by the spring r, then in contact with the handle c, is intercepted by the battery p, whose current is in the opposite direction. As this current is only half the strength of that from the large battery, it might be thought that a part would flow on this side; but as the current of the large battery is weakened by the resistance R, and seeing it is only a portion of the current through E which can pass that way—in fact no current passes on that

side—the current of the battery P goes almost entirely to excite the electro-magnet of the other station to the right, flowing to earth by the spring s'. The result then is the same as in an ordinary transmission.

Now if the two stations send at the same time, the two keys being depressed the currents from the two line batteries join at the two stations, and would produce double the action on the receivers if they did not pass the branches R and R', and the two batteries p, p', which act to re-establish the equilibrium. In short, the current from the battery P arriving at the right hand station, passes partly by the electro-magnet E', and partly by the lead R'. In this path it is forced into a' by the battery P', but it is also equally forced into E' by the battery p', with which it is joined through contact with r and the handle c'. As the resistance in the branch R' is double that of the electro-magnet E', and that on the other hand the battery p is only half as strong as P, there is balance in the effects produced, and the result on the receiver is the same as if the sending battery only had reacted. Of course the same effects are produced at the other station, since the arrangements of the circuit are exactly symmetrical.

§ 3.—*Simultaneous Transmission.—The Harmonic Telegraph.*

So far back as 1870 Varley proposed a multiple telegraph based upon the plan of transmitting into a telegraph line rapidly interrupted currents corresponding to definite musical notes, broken up into dot and dash signals by means of a key. This harmonic telegraph presented many ingenious features, but was never brought into practical use.

An American electrician, Elisha Gray, in 1874-5, designed a system of simultaneous transmission in which the principle is different from that above described, and depends on the synchronism of sonorous vibrations propagated by electric currents. Hence the name *harmonic telegraph* given to the system.

Gray's harmonic telegraph solves the problem of the simultaneous transmission of several signals in the following way. Each signal emanating from a special transmitter, corresponds to a current of

particular strength, and the variations of the current are connected with the vibrations of a plate giving out a determined and fixed sound. The line wire transmits this varying current, this electric wave, to the receiving apparatus, and communicates the vibrations of the receiver to an elastic plate, because this plate is adjusted so as to be affected by these particular vibrations being tuned in unison with the transmitter. Two, three, or four pieces of apparatus work at the same time, transmitting at once on the same wire so many distinct electric waves; these waves are separated at the receiving station, each moving the corresponding synchronous receiver, and each signal or message, after having travelled along the line wire with all the others is thus transmitted and received independently.

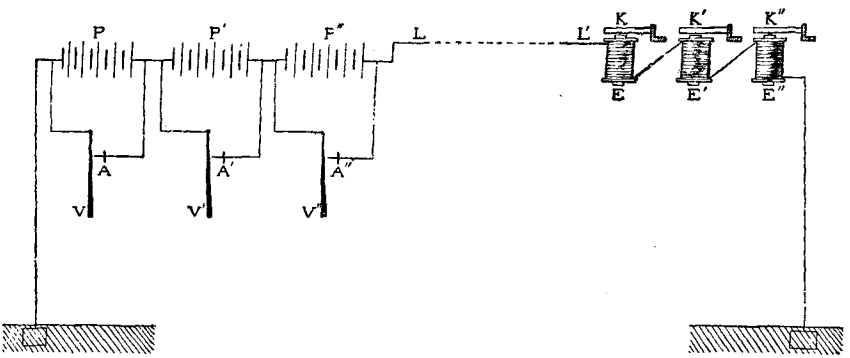

FIG. 401.—Gray's Harmonic System.

The harmonic telegraph reduced to its essential parts comprises P P' P'' (Fig. 401), the battery of the sending station which is connected on one side to earth, and on the other to the line wire. This battery is divided into as many groups as there are special transmitters in the station, and on each of them is placed a circuit, which includes a vibrating plate V V' V'' and a contact screw A A' A''. The currents which are sent into the line from the sending station pass at the receiving station through the coils of the electro-magnets E E' E'' arranged in series. The vibrating pieces K K' K'' placed according to their poles, and firmly fixed at one of their ends, are regulated so as to give three distinct notes in unison with the three vibrating plates at the sending station. These vibrations, each started by a battery and special electro-magnet, are kept up continuously and

with a given amplitude and frequency, which causes each to give the fundamental note for which it is regulated. Each time that one of them touches its contact the current is weakened, because of the closing of the corresponding derived circuit, but again acquires its original strength as soon as contact is broken. Hence the making and breaking of the current, the rapidity of which depends on the number of oscillations of the vibrator, determines as many electric waves as there are distinct vibrators. These three series of simultaneously transmitted waves will find on arriving at the receiving station three

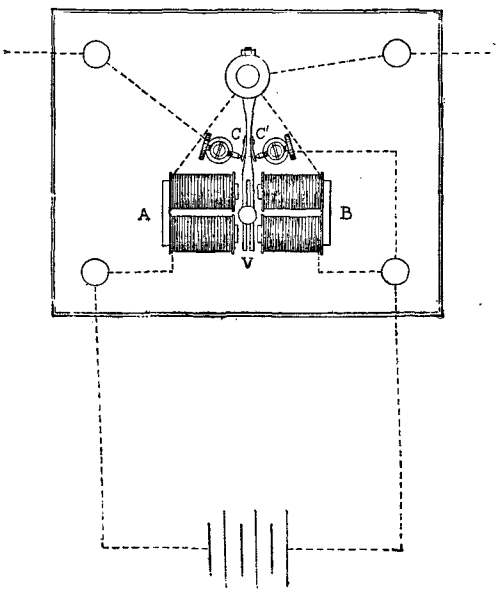

FIG. 402.—Vibrator of Gray's Harmonic Telegraph.

pieces in tune with them, each of which will vibrate under the sole influence of its synchronous wave.

Let us now suppose that you stop one of the vibrators, immediately the corresponding electric wave is suppressed, and the contact piece of the receiver which it causes to vibrate is also stopped. If the stoppage of the vibrator is short, that of the receiving piece will be equally so; and similarly if it is long. A continuation of long or short stops at the transmitting station will be identically reproduced at the receiving station; and if for example they correspond with the

signals of the Morse alphabet, it is clear that the result will be a message transmitted, which in America is received by a *sounder*, and which can be received by an ordinary Morse apparatus. The three or four transmitters work simultaneously, and the vibrating contact pieces of the receivers are affected at the same time, but each is only affected by the stops of the corresponding vibrator. It is clear then that simultaneousness of transmission is assured by this system.

The details of the working parts in Gray's harmonic telegraph may be followed by reference to the models shown at the International

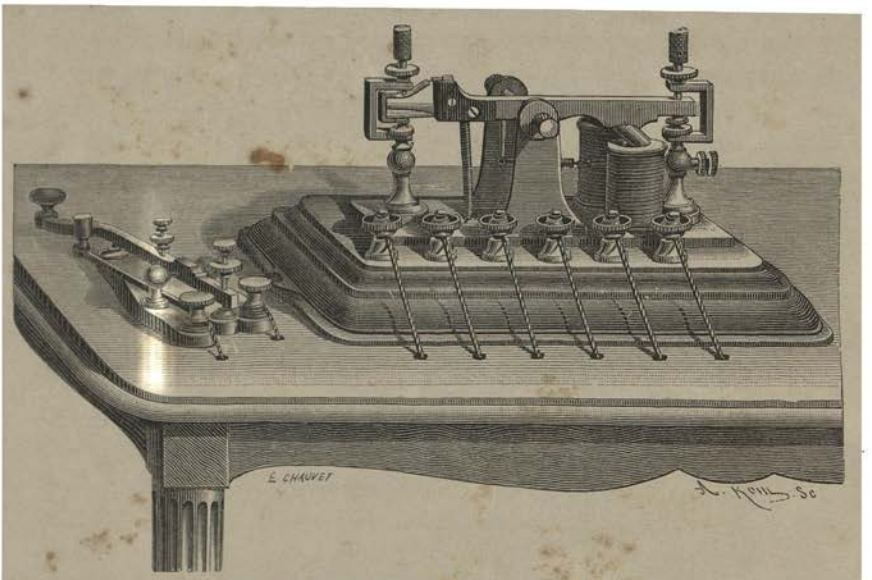

FIG. 403.—Transmitter of the Harmonic Telegraph.

Electrical Exhibition of 1881. Fig. 402 represents the arrangement of the vibrator, the plate V is fixed at the point *o*, and vibrates under the alternate influence of the electro-magnets A, B, whose cores are magnetized simultaneously by a special battery, but one, A, for example, wound with wire of a convenient length, is calculated to offer five or six times the resistance of the other. Attracted at first by the strongest, the plate touches a contact which shunts the current and weakens it; the other electro-magnet becomes stronger in its turn and attracts the plate. Then the current being again broken, the shunt opens and the electro-magnets resume their original

relative intensity, A again attracts the plate, and so on. The *transmitter* (Fig. 403) consists of a Morse key, seen on the left, and of a special arrangement having for its object the regulation of the strength of the currents, which the stoppages of the vibrations would otherwise cause to vary too much.

Fig. 404 represents the *receiver* and *sounder*. This apparatus is generally used in the United States, where the clerks charged with receiving have only to listen to the signals, without preserving the written records. The principal part of the receiver is a steel rod firmly fixed at one end, and regulated so as to give a note perfectly in unison with that given by the plate of the corresponding vibrator.

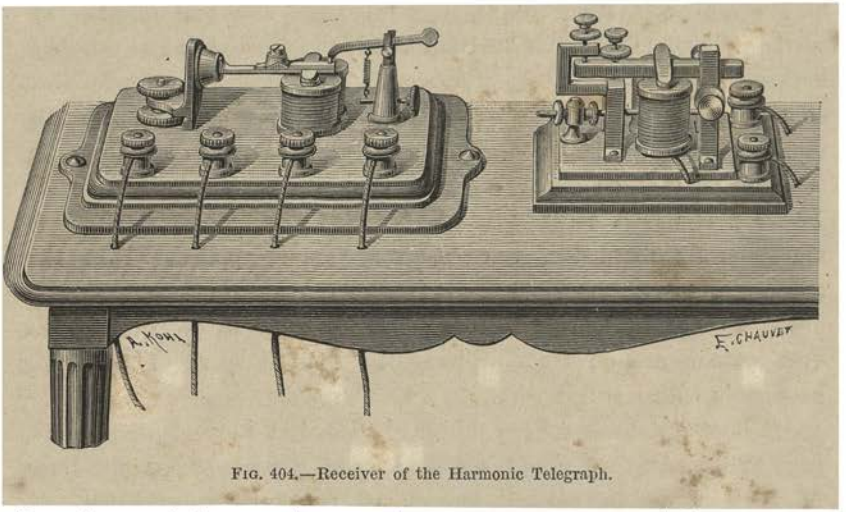

FIG. 404.—Receiver of the Harmonic Telegraph.

Its other end is opposite an electro-magnet traversed by currents sent into the line; but in order that the variations produced in these currents by the transmitters may affect the steel rod, they must agree with the number of the vibrations which correspond to this note. There is then a choice of the vibrations from the current made by the receivers themselves.

The experiments on Gray's harmonic telegraph made in America during two months on the Western Union line between Boston and New York (320 kilometres) gave excellent results. Although they took place under unfavourable conditions the success was complete.

In one experiment[1] five operators sent in the space of nine hours

[1] *La Lumière Electrique:* January, 1882.

2,124 messages, 236 per hour; that is 47 by each man per hour. Another time four skilled operators transmitted in five hours 1,184 messages; that is 59 by each clerk per hour.

The most recent harmonic telegraph is that known as the Phonopore telegraph, invented by Mr. Langdon Davies, to which reference has already been made.

§ 4.—*Multiple Transmission.—Meyer's Telegraph; Baudot's Telegraph.*

The rapidity of any method of transmission depends on the number of currents which this system is able to send along the wire in a given time, for example, in a second. The real number of currents found in practice does not reach the greatest ideal number indicated by the capacity of the wire. This rapidity depends also on the number of currents which each signal, letter figure, or blank separating the words, demands, also on the skill of the operator. It is admitted that, on an average, the ordinary Morse apparatus sends 1·5 or 2 signals a second; Hughes's reaches 3, and these numbers are generally doubled if the duplex system is applied. Now the automatic telegraphs show that 100 currents can be sent, that is about 25 signals per second on a wire (with a Morse), so that the best systems are far from utilizing the highest speed of signalling attainable with a single wire.

A new system has been designed, the first idea of which dates from 1860. At that time, an inspector of French telegraphic lines, M. Rouvier, published his project of multiple transmission, the general principle being to divide the time of transmission into regular and periodical intervals, each period of which belongs to a distinct manipulator; a certain number of operators use the line wire in their turn, so that it is constantly in use. The first system of multiple transmission based on this principle was invented by Meyer in 1871, and applied to the Morse signals; it was used on the line from Paris to Lyons, and on the chief lines in Switzerland and Austria.

The sending apparatus of *Meyer's multiple telegraph* has a key-board consisting of four white keys and four black ones. On pressing down a black key a short current is produced—a dot; on pressing a white one you have a line or dash; on depressing

simultaneously any two or more you have a combination of dots and dashes that form, as in the Morse, a letter, figure, or any other sign.

The receivers have each a quarter of the circumference of a coil for printing (if there are four manipulators). One end of a lever forming the armature of an electro-magnet presses the paper against the coil during the passage of the current: the result is a dash, or a dot, on the strip unrolled with a speed of three millimetres per turn before the cylinders which bear the fractions of the coil. The signals are thus printed transversely. Hence the impossibility of confusion between two consecutive letters, and also a great reduction in the length of strip for the message. Each manipulator requires two receivers, one at the sending station, the other at the receiving station, thus giving double control.

But the principal part of Meyer's telegraph is the *distributor*, which directs the battery current to the line wire, so that the currents from each manipulator pass successively to the corresponding receiver of the sending office, and thence to the receiver in the receiving office. Meyer's distributor is a fixed metal wheel, insulated and divided on its circumference into forty-eight equal parts. Each quarter of the circle, formed of twelve divisions, belongs to the service of one manipulator. Four groups with double divisions are joined by a bunch of eight insulated wires to the eight keys of the keyboard, the four other divisions in the groups are joined to earth.

Clock work regulated by a conical pendulum drives at the same time the coils of the receivers, and an elastic rod or brush which sweeps round the circumference of the disk of the distributor. This brush puts each manipulator, and the corresponding receiver, in contact with the line during a quarter of the rotation. Thus each of the four clerks has the line at his disposal during that time. He is warned by the sound of a little lever the moment when the signal he has sent is finished. Of course the essential condition of a system of this kind is simultaneousness of movements in the apparatus at both offices. It has been already shown how this condition can be realized in the description given of Hughes's printing telegraph.

Baudot's multiple printing telegraph prints its despatches in

ordinary characters, like the Hughes's apparatus. It is a marvel of precision and rapidity. A complete installation for one wire between two stations consists of six manipulators, one distributor, and six printing receivers for each office. The same operators send and receive. The *manipulator* in Baudot's system, represented in Fig. 405, consists of a keyboard with five keys divided into two groups; one group has two keys worked by the middle and forefinger of the left hand, the other has three keys worked by the forefinger the middle finger and the ring finger of the right hand.

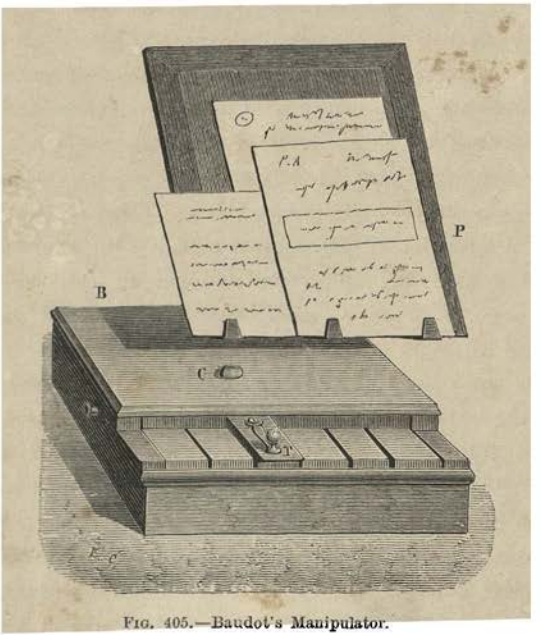

FIG. 405.—Baudot's Manipulator.

The band which separates these two groups leaves a space for the thumbs, it carries a little handle T, which is used according to its position to put the manipulator ready for receiving or sending.

The box B contains the contacts which serve to put each key in communication with the batteries, and with the line wire. In the state of rest the five keys of the manipulator allow *negative* currents to pass while the distributor is in the proper position; on the other hand, when the keys are depressed, being worked, they send *positive* currents into the line. Thus during each turn

of the distributor there are for each of the six manipulators five currents, positive or negative, and it is from the combinations of these currents on the five keys that Baudot has made all the signs necessary for telegraphic communication. The number of combinations of the five signs being 32 or rather 31 (since the manipulator at rest gives the first), there are 31 signals, which are doubled by an artifice similar to that employed in Hughes's system. The following table shows the combinations of the currents, and consequently the fingering of the manipulator:

Rest	−	−	−	−	−	Error	−	−	−	+	+
A or 1	+	−	−	−	−	N or N°	−	+	+	+	+
B „ 8	−	−	+	+	−	O „ 5	+	+	+	−	−
C „ 9	+	−	+	+	−	P „ %	+	+	+	+	+
D „ 0	+	+	+	+	−	Q „ /	+	−	+	+	+
E „ 2	−	+	−	−	−	R „ —	−	−	+	+	+
É „ etc.	+	+	−	−	−	S „ ;	−	−	+	−	+
F „ F	−	+	+	+	−	T „ !	+	−	+	−	+
G „ 7	−	+	−	+	−	U „ 4	+	−	+	−	−
H „ H	+	+	−	+	−	V „ '	+	+	+	−	+
I „ O	−	+	+	−	−	W „ ?	−	+	+	−	+
J „ 6	+	−	−	+	−	X „ ,	−	+	−	−	+
K „ (	+	−	−	+	+	Y „ 3	−	−	+	−	−
L „ =	+	+	−	+	+	Z „ :	+	+	−	−	+
M „)	−	+	−	+	+	T O	+	−	−	−	+
Blank figure	−	−	−	+	−	Blank letter	−	−	−	−	+

The three first signs correspond to the three keys to the right of the manipulator, the two following to the keys on the left. If for example the letter M is to be sent, the middle finger of the right hand presses the corresponding key, and the two fingers of the left hand put down their keys simultaneously; the signal sent will then have the following combination of currents: − + − + +.

These currents are sent into the line wire by the *distributor*, and received at the receiving office. The distributors consist of disks of insulating material with metallic surface pieces connected with the keys of the manipulators. Each disk is divided into six equal sections, having the same number of contact pieces as there are keys in each manipulator. Each section is connected to a separate set of instruments, but there is also a special section called the *correction section*, its function being to transmit currents to regulate

the motion, or to obtain synchronism between the two distributors at the sending and receiving stations.

A lever, free to move round the axis or centre of the disk, carries a contact having a uniform rotatory motion. During a complete turn, this contact passes successively over the six sections, and as it is in connection with the line, it sends the currents which it receives from the five divisions of each section, these currents being negative or positive, according as the keys of each manipulator are at rest or pressed down. From Fig. 406, the path of the current for a signal sent by one of the six sections A, B, C, D, E, F, may be followed. The keys of the corresponding manipulator when at rest put the divisions 1, 2, 3, 4, 5 of the section A in connection

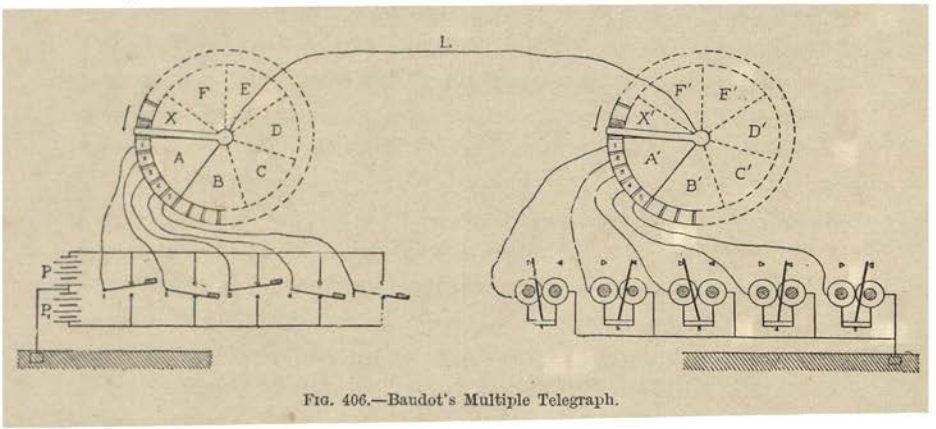

FIG. 406.—Baudot's Multiple Telegraph.

with the negative pole of the battery, the positive pole being to earth. If on the contrary any one of them is pressed down it comes in contact with a button called the *working button*, which unites the corresponding division to the positive pole of a second battery, the negative pole being to earth. In the left-hand part of the Figure, representing the sending station, the keys 1 and 3 are at rest, whilst the others 2, 4, and 5 are depressed As the contact passes over the five division of section A, the currents sent into the line will succeed each other in the following order : $- + - + +$, and the signal corresponding to the letter M will be sent. Continuing its movements over the other sections B, C, D, E, F, the contact piece will transmit successively the positive and negative currents sent for these sections according to the position of the keys on each manipulator. And

so on for each rotation of the contact-piece over the divisions of the disk.

Now in the receiving station there is a *distributor*, like the apparatus just described, divided into six sections, with another section for correction, and driven at an equally uniform speed. The contact which moves over the divisions of the disk, passes over each, at the same instant as the contact-piece of the distributor at the sending office, and the synchronism of their movement is constantly regulated or corrected. But each division, in the receiving instrument, is attached to an electro-magnet which, as soon as the contact-piece passes, is excited by the current sent into the line wire. A polarized armature oscillates between the poles of the electro-magnet, and is limited in its movement by two studs against which it rests, depending on the direction of the current transmitted. In examining the position occupied by the five arms after the contact-piece passes over the section A, it will be seen that they translate the combination — + — + + that we supposed sent by the corresponding manipulator.

Fig. 407 shows the distributor $\frac{1}{8}$ of its full size. P is a grooved pulley, driven by a special motor, which turns the horizontal shaft A; this shaft is furnished with a flywheel, shown connected to the pulley, and a speed regulator, a vibrating plate in a coil T. The shaft carries at one end a pinion, gearing into the bevel wheel R. It is the vertical axle of this wheel which carries the arm F furnished, not with one, but with ten contact-pieces, in the form of a brush, like that on the commutator of a dynamo machine.

The horizontal ebonite disk C supports nine concentric circular rows of metal contacts each travelled over by one of the nine contact-pieces arranged on the movable arm. The two first outside rows are used for transmission; one of them is attached to the line, the other successively to each of the manipulators, which we have seen can make contact with the negative pole, or with the positive pole. The next two rows are used for receiving; one serves as control at departure, and for printing the message, a special battery is devoted to this: the other row communicates with the electro-magnets of the receiving relay. The fifth row, the contact of which is connected with that of the eighth, only contains four very short contacts, in each section, which serve to make up for the slight errors of synchronism

between two consecutive currents, and to give certainty to the working of the receiving relay. For this purpose also row eight, which is continuous, is connected to earth. The contacts of rows six and seven send the current from a local battery to different contacts of the sixth row; one communicates with the manipulator, and produces a signal which warns the clerk, the moment before the contact-piece comes on the particular section belonging to him, and when he ought to arrange the combination of keys for the following signal. The ninth and last row has a contact which is connected with a tenth contact-piece passing over the fourth row a little before the contact belonging to

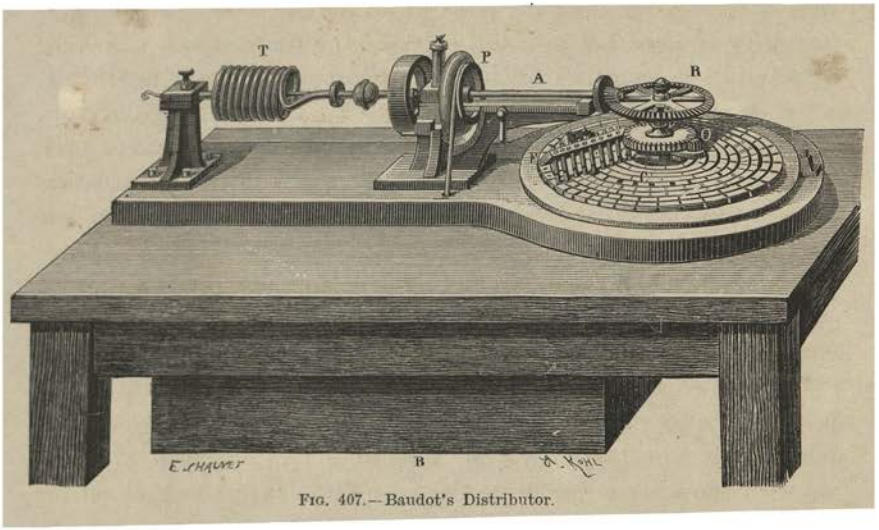

FIG. 407.—Baudot's Distributor.

that row; this sends a negative current from a local battery to the armatures of the receiving relay to bring them to rest.

The currents from the seventh section, or *correction section* are for a special electro-magnet, to cause the engagement or the release of the contact handle in the distributor at the receiving station, when it is necessary to regulate its motion with that of the distributor of the sending station at its normal speed. This regulation is effected by a satellite pinion o moved by the mechanism of the relay.

Fig. 408 represents the present arrangements of the receiving relay. A A are the arms of a horseshoe-magnet the curved part being imbedded in the wooden base. Between the poles of this magnet there is a soft iron cylinder divided into two unequal por-

tions by a piece of copper, carrying a transverse rectangular plate, which rests on two points, at the height of its own axis on the poles themselves, and thus constitutes a polarized yoke or armature

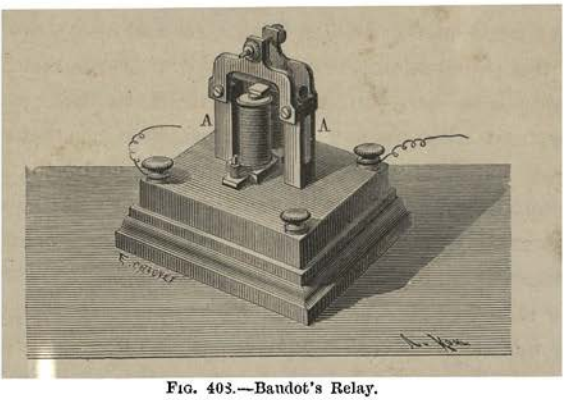

FIG. 408.—Baudot's Relay.

capable of vibrating round its axis. Under the influence of that one of the poles in contact with the armature, the transverse plate oscillates to the right and left, according as it is attracted by one or other of the poles of an electro-magnet placed underneath and

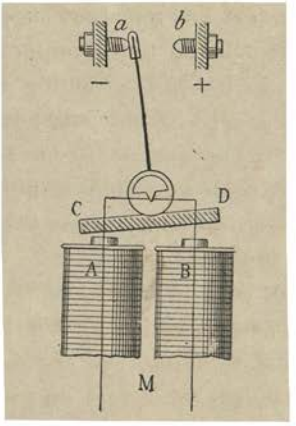

FIG. 409.—Section of Baudot's Relay.

opposite, and whose coils receive the positive or negative currents from the line. The oscillations of the armature are increased by a soft iron rod whose end is placed between two studs, one for rest *a*, the

other for work *b* (Fig. 409); the latter only has a silver contact to establish electric communication.

When a negative current comes from the line, the cores B and B of the electro-magnet are polarized and cause the armature rod to occupy the position to the left against the stud *a*; the armature is moved to the right when the positive or opposite current is sent: we have already seen how the coils are joined to the contacts of the distributor, and to earth; the five armatures of the relays, when the receiver contacts have passed into the corresponding section, become arranged so as to preserve the signal received; then by sending a local current to the contact of the seventh piece the same combination is transmitted to the electro-magnets of the receiver, where the impression is to be made.

In the first instruments the arrangement was different. On the end of one of the poles of the horse-shoe magnet there was a notch into which was placed, by a sharp point, a vertical armature of soft iron. The middle of this armature, being opposite the cores of two straight electro-magnets placed on the same axis, oscillated between these cores, its upper end oscillated at the same time between two studs, one of which corresponded to negative and the other or working stud to positive currents. The armature was polarized by the magnet with which it was in contact, and remained supported by the attraction of one or other spindle, till the tenth contact of the distributor had brought it to rest, a little before the sending of the following signal. Each group of the two opposite sections possessed a series of five relays and there was an insulated relay used for correction. With the new arrangement, each manipulator possesses five relays, and independent receivers, so that on the same table in an office with six transmitters there are thirty relays.

The above only deals with the parts of Baudot's telegraph which concern transmission and reception. We have seen how the six manipulators of one station, and the six corresponding receivers[1] can exchange their signals in turns, and continuously, by means

[1] It is of course understood that the six manipulators in the station are not generally all at once occupied with transmission; some transmit, whilst others receive. It is only necessary to pass from one to the other of these functions of the apparatus, to establish convenient communications between each group of sections, and we have seen what the position of the handle of the manipulator determines at will, transmission, or reception.

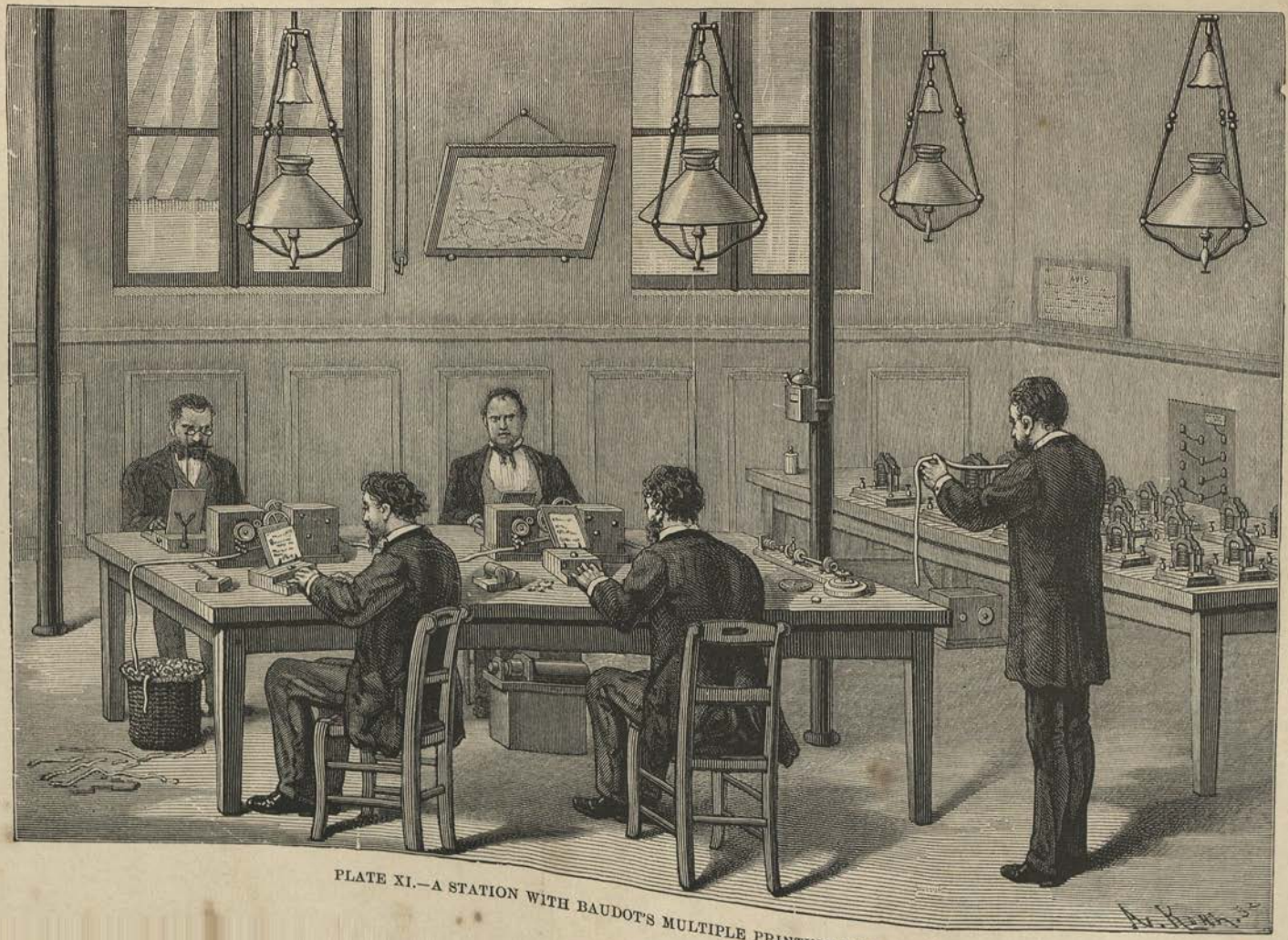

PLATE XI.—A STATION WITH BAUDOT'S MULTIPLE PRINTING TELEGRAPH.

of a common distributor which thus utilizes all the delivering capacity of the line wire.

The speed when the apparatus is at work, gets up to 150 or 180 turns per minute, which makes 2·5 or 3 turns per second; an easy calculation shows that each manipulator is put into communication with the corresponding receiver, once every turn during the interval of time contained between $\frac{1}{16}$th and $\frac{1}{20}$th of a second. It is during this short interval that the clerk transmits the letter, or signal, made up of the combination of the five keys; between one turn and the next, the preparation of the signal which ought to follow takes place. With the speed we have mentioned an office with six clerks can transmit in any direction 900 or 1080 signals a minute, that is, 54,000 or 64,800 signals an hour. Reckoning blanks for the separation of the words and taking an average of five letters a word, that would make 450 or 540 despatches, each containing twenty words per hour.

In reality, the interruptions, errors, and repetitions reduce the rate. Still the delivery by a wire with Baudot's apparatus is not less than 300 despatches, of twenty words each, in an hour; this very much surpasses in rapidity any of the previously described systems, and besides, the despatches are received printed.

How do the combinations of positive and negative currents sent by one section, and received by the electro-magnet relays, or receivers, of the other corresponding section, become transformed into letters printed on a continuous strip of paper which is unrolled at both stations? We shall try to make this clear, without entering into the minute details which would be necessary for a complete knowledge of the mechanism.

The *receiver* comprises three principal parts; we have already described the receiving relays. Figure 410 represents the printing apparatus, properly so called, which being very much like the printer of Hughes's apparatus, does not need a special description. But in order that the type wheel E may fulfil its function, and that the printing-cam should be raised at the moment when the letter wanted passes in front of the paper, and that the paper should rest against the letter, a special mechanism is necessary to establish a correspondence between this cam and the combination of the five branches of the electro-magnet receivers. This mechanism has

received the name of *combiner*: it is the most ingenious, and certainly the most original part of Baudot's telegraph.

The *combiner* is composed of a fixed horizontal disk, on which are traced five rails, concentric with the axis of the disk, each divided into two traces, and separated by zones the same width as the traces. The 360 degrees of the circle are divided by radii into thirty-one sectors of ten degrees each, corresponding to the thirty-one effective combinations or signals of the system, and the remaining 50 degrees

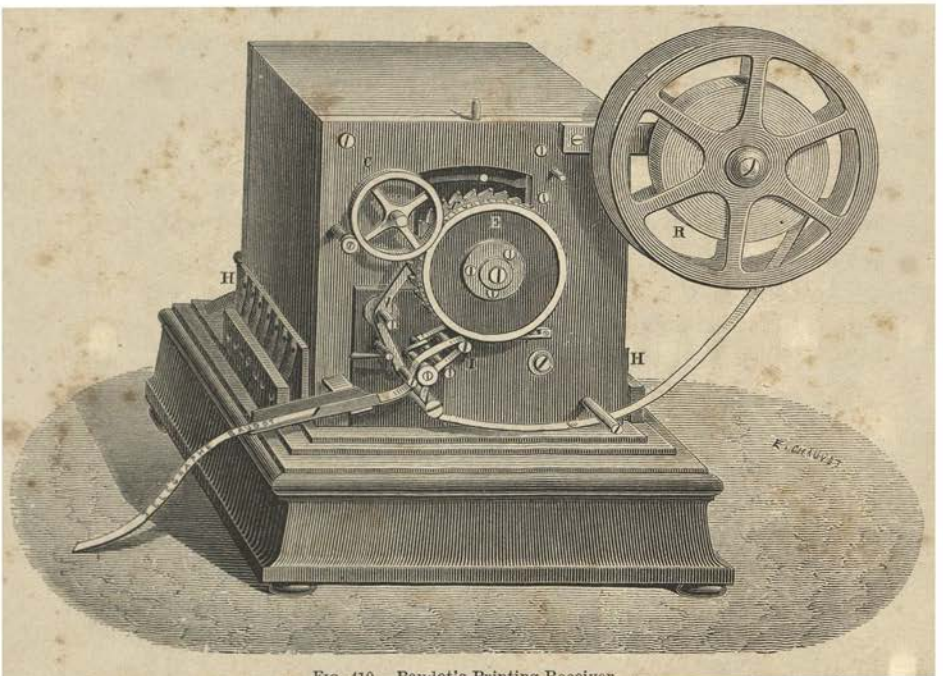

FIG. 410.—Baudot's Printing Receiver.

form a *neutral sector*. Of the two traces on each rail the outer one corresponds to the position of the armature of the electro-magnetic receiver when at rest; the inner one to the working position. For this reason the exterior trace is called the *resting track*, and the interior one, the *working track*. Both are hollowed out in the form of a groove, but at different depths according to the part of the rail and section. Let us consider for instance the letter M, on the twentieth section; we know that the combination is represented by the signs $- + - + +$. In the rails one and three, it is the rest-

ing track which will be hollowed out the deepest; whilst in the rails two, four and five the working track will be lowest, as shown in section in Fig. 411.

Let us now imagine a shaft rotating about the axle of the disk. It has the same angular speed as the type wheel. This shaft bears a chariot, composed of a frame in which are fixed five levers *t t t* . . . (Fig. 413) terminated by vertical pins *g g g* . . . (Fig. 412) resting on

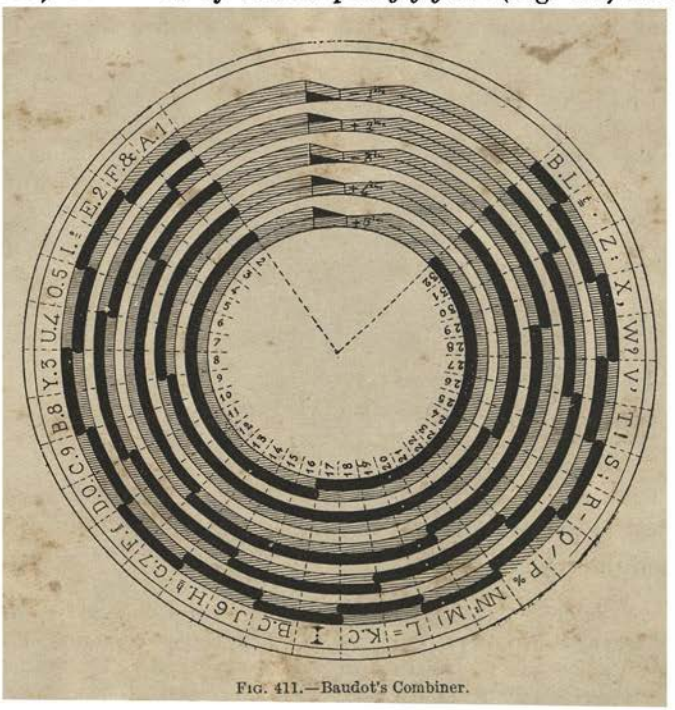

FIG. 411.—Baudot's Combiner.

the bottom of each rail. The levers can oscillate in the plane of the frame, and can turn so as to place themselves in the resting track, or in the working track. This turning takes place whilst the chariot goes over the neutral sector, and is determined by a mechanism fixed to the movement of each armature, in the electro-magnet receivers. Let us suppose that these electro-magnets have received the combination of signs for the letter M. In this case, the levers, as well as the pins with which they are provided, are directed into the tracks of their respective rails as follows: the first lever into the resting track, the second into the working track, the third into the resting track,

the fourth and fifth into the working tracks, thus the five pins are all, when passing above the sector M, in the positions shown in Fig. 412. On the contrary, in passing above any other of the thirty sectors, there will always be at least one of the pins which will remain supported at the ordinary level of the rails. But when opposite the twentieth sector the frame which bears the levers, not being supported is lowered by a spring. This moves the printing cam, and the paper strip rests against the letter of the type wheel which is opposite to it

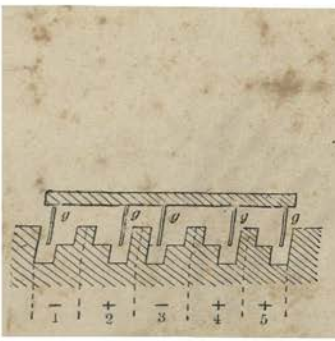

FIG. 412.—Section of the five tracks at the twentieth sector.

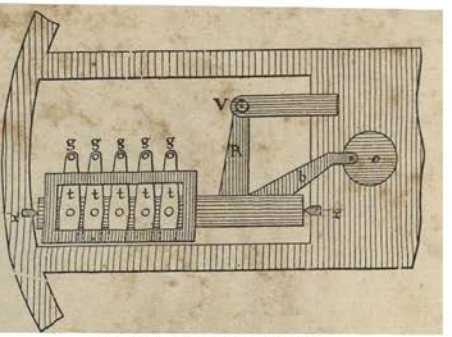

FIG. 413.—Combiner Chariot.

at that moment. Now this is the letter M, since the rotation of the type wheel is perfectly simultaneous with that of the chariot round the axis of the combiner.

In the first models of the receiver this apparatus was double, and served for a group of two opposite sectors; the five relays were common; the combiner had two distinct chariots, and the printing parts were also distinct. But the solidity of the station receivers having proved inconvenient in practice, Baudot constructed some new models of single receivers, like his first apparatus.

The combiners in these new receivers have been completely modified. The principle remains the same, that is, that the motion which produces the impression of a signal on the type wheel, is always given by the five pieces dropping into the hollow grooves of the resting and working tracks of the combiner. But, thanks to an ingenious combination in the succession of the thirty-one signals that constitute the vocabulary, the five rails are reduced to one. Instead of arriving simultaneously at the positions which agree with the received combination, the five pieces are placed successively in one or other of the tracks.

CHAPTER VI.

TELEGRAPHIC LINES.

§ 1. *Aerial Telegraph Lines.—Subterranean Lines.*

AN aerial telegraphic line is made of insulated metal wires generally supported on wooden poles at equal distances apart between two stations. At first these wires were of copper, 2 millimetres in diameter. The metal chosen had the advantage of being a very good conductor of electricity; but besides its great price, it had the inconvenience of losing its elasticity and breaking by changes of temperature. Copper is now generally abandoned, having been replaced by iron wire, 3, 4, or 5 millimetres in diameter, which is stronger and less costly; in France wire of 3 millimetres is used on lines along railways, 4 millimetres on the lines of the interior service, and 5 millimetres for international use.

On long lines, where it is important to have the least possible resistance to the passage of the current, iron wire of 6 millimetres or 6·5 millimetres is employed. In England especially these large wires are used. Formerly the sizes of wires used to be specified in terms of the "Birmingham wire gauge," but this has been abandoned by the British Postal Telegraph authorities, since the reputed gauge was not accurately carried out in practice. The British specifications for tender now always state sizes in actual measure of the diameter in "mils," *i.e.* in thousandths of an inch. But since the electric resistance of different qualities of iron varies considerably, the latest method adopted by the British Postal Telegraph authorities to describe a wire is in terms either of its weight per mile, or else in terms of its electrical resistance per mile. The standard size of

iron wire used in Great Britain is 171 mils or 0·171 inch in diameter. One mile of this wire has a resistance varying from 11 to 18 ohms; and the weight of a mile of it is about 440 lbs. Swedish charcoal iron conducts better than less pure sorts, its resistance being about 11 ohms to the mile; whilst ordinary puddled iron varies from $13\frac{1}{2}$ to 15 ohms per mile.

Iron wire for telegraph lines is galvanized, that is, after having been scoured in acidulated water, it is covered with a thin layer of zinc by drawing it through a bath of the molten metal. This preserves the iron from rusting, and besides, by galvanic action, prevents oxidation of the parts accidentally uncovered.

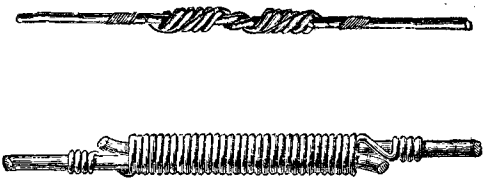

FIG. 414.—Joints on Telegraph Wire.

The method of joining the ends of the line wires has much to do with the good electric conductivity of the wire. Fig. 414 gives two ways of making joints, one suitable for copper, the other for iron wires. The latter, known as the Britannia joint, is made by first wrapping a thin binding wire over the iron wires and then uniting the whole with solder. Iron coverings have also been employed, in which the ends of the wires are placed, nipped, and flattened, then covered with solder poured into the opening of the covering. This method, adopted in France, gives good results, both as regards contact and solidity.

The telegraph posts are made of firwood, preserved by the injection of an antiseptic solution, generally sulphate of copper.[1]

[1] [It has been shown by experience that timber is best preserved by *creosoting*. The posts are placed in an air-tight vessel, and the air and moisture extracted from the pores by an air-pump. The creosote is raised to a temperature of 212° F., and forced into the pores at a high pressure, 120 lbs. per square inch.—ED.]

To avoid breakage in damp or rainy weather, the wire is not directly joined to the posts. It is supported on *insulators* of glass or porcelain, sometimes of ebonite—hard vulcanized india rubber. In England brown stoneware is almost universal, whilst in America glass is almost as exclusively used. Fig. 415 and Fig. 416 show how these *insulators* are fixed on the posts, and how they support the wires, either in the straight parts of the line, or on curves requiring a special arrangement to avoid the effects of traction.

The distance between the posts is on an average 100 metres,

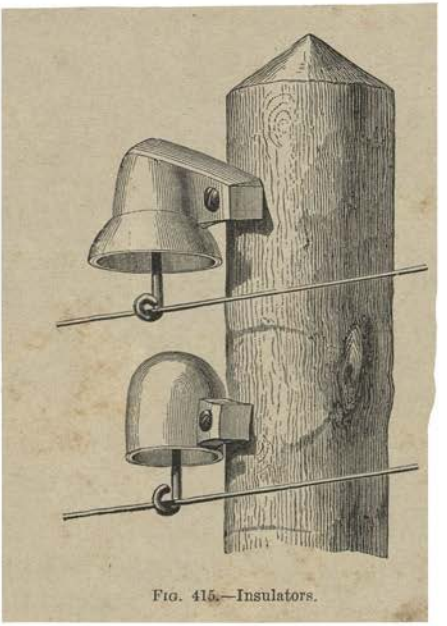

FIG. 415.—Insulators.

generally less at the turns and more in the valleys, where sometimes the distance is 400 or 500 metres. The height of each post is from 8 to 10 metres, and higher when the line goes over rivers, roads, &c. In towns the porcelain insulators are fixed on wooden brackets, fastened against the walls of houses, or other buildings, sometimes on small posts passing over roofs; but for some time past, it has been found preferable to replace such aerial wires by subterranean ones laid in tunnels and subways.

Each post may support several wires, fixed at intervals of 25 or

30 centimetres, alternating them on each side, before and behind, so as to balance the weights which tend to pull down the post. From kilometre to kilometre, that is the usual length of each wire, tenders are put up fixed in the same way on porcelain insulators. The iron plate uniting the two axes serves to join electrically the two portions of the wire (Fig. 417). It is necessary to stretch the wires with considerable force in order to prevent them from touching each other.

In England and Germany other methods are used to keep the wires taut, as shown in Figs. 418 and 419.

When the electric telegraph was first used, the system of sus-

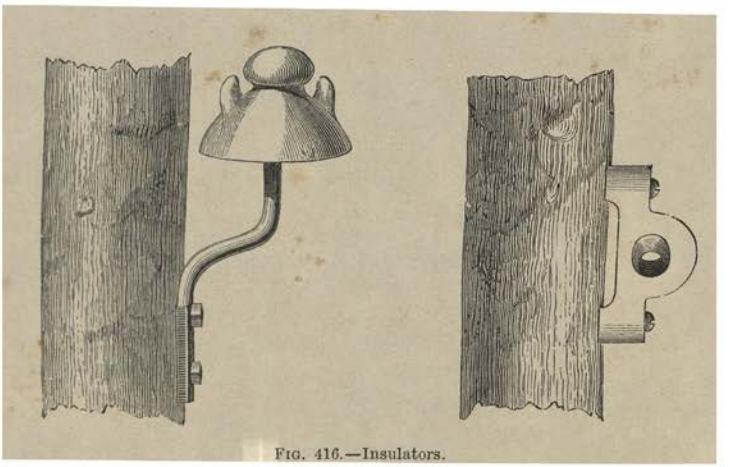

FIG. 416.—Insulators.

pending wires in the air was not thought practicable; it was supposed that the electric leakage from various causes would be too great: also that the wires would be exposed to destruction. In Prussia and Russia the wires were laid in the earth, at a depth between two and three feet. But this system of line telegraphs, much too expensive, has been abandoned almost everywhere; it was for some time continued, and is so still in portions of the line that penetrate to the interior of the towns, or which have to traverse railway tunnels. In this case the wires were of copper, each covered with a layer of gutta-percha, and connected together into a cable, which was itself surrounded by fine wire tarred. This cable was then placed inside creosoted wooden troughs, leaden or iron tubes laid about a yard deep

on a bed of sand, or sifted earth. Such was the subterranean line at Paris connecting the central telegraphic administration to the

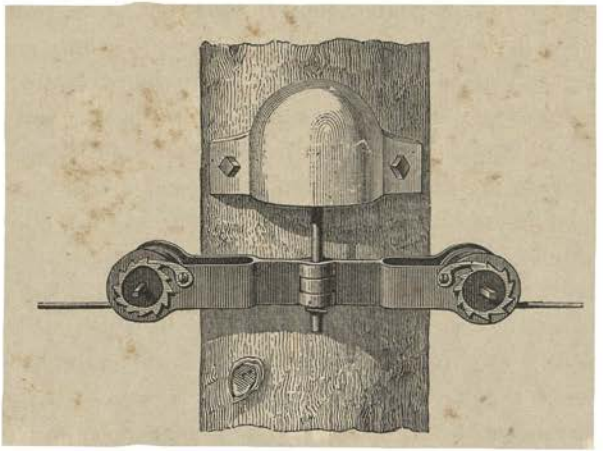

FIG. 417.—Wire-stretcher.

Observatory, to the Luxembourg, to the docks of Montparnasse and the Lyons and Orleans railways. It has given results only partially

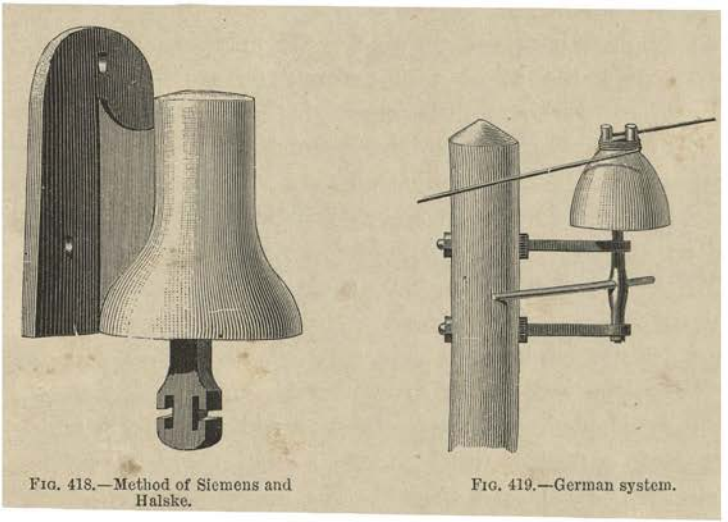

FIG. 418.—Method of Siemens and Halske.

FIG. 419.—German system.

satisfactory, and many times the wires have become so impaired that it was necessary to do away with them.

Another system consisted in employing galvanized wires like those

of air lines, united in blocks of four, six, or ten wires, insulated from each other by masses of bitumen. The cable thus formed was buried in a mass of bitumen poured into the bottom of a trench more than a metre in depth. Such was, at Paris, the line uniting the central telegraph office to the Tuileries, the Louvre, the Hôtel de Ville, the Bourse, the Préfecture de Police, but it only worked imperfectly; such also was a line of 1200 metres long established at Bordeaux. This method gave excellent results, but the trenches needed to be guarded from percolation of moisture and gaseous products which at length damaged the bitumen.

In tunnels, the wires were fastened to the vaults, but protected against damp by a layer of gutta-percha which joined them into a cable; the insulating envelope however changed very rapidly under the action of atmospheric agents. As we have said, subterranean lines were a few years ago an exception: in the net-work of general electric telegraphs they have now become more and more numerous. But precisely, as the use of this advantageous method of correspondence, in spreading, increases the demands of the service, so the inconveniences of the air-lines are more and more felt.

These inconveniences are great; the influences of atmospheric electricity on the wires, during storms, for example, disturb the regularity of working; inclemency of the weather, winds, frosts, snow, and lightning cause accidents, which put the lines temporarily out of repair. During the winter of 1879 wires were broken in many places by the weight of snow on them. Besides telegraph wires in times of war are exposed to violence and easy destruction.

We cannot enter into the details of the technical methods employed for laying subterranean cables, an operation which has only an indirect relation to our subject.

Within the last four or five years Germany and France have resolutely adopted such lines: we may add that Great Britain in 1873 made a trial of this kind, and a line of 900 miles long was constructed; it did not succeed, and in six years it had to be replaced by an air line.

In 1876, Germany tried an experiment between Berlin and Halle, a distance of 193 kilometres, and a cable of the type desired was laid. The results being satisfactory, other lines were constructed, and on January

1st 1881, there were 4000 kilometres completely laid. At this time Berlin was connected with Mayence *viâ* Halle, Cassel, Frankfort-on-the-Maine, with Cologne *viâ* Magdeburg, Brunswick, Hanover, Minden, Munster, Wesel, and Dusseldorf; with Hamburg, and Kiel. A line existed from Frankfort-on-the-Maine to Strasbourg *viâ* Darmstadt, Mannheim, Carlsruhe, Baden, Kehl; another from Cologne to Metz *viâ* Coblentz and Trèves. Metz and Strasbourg also have subterranean communication.

Other branches of less importance were also constructed at the same time; similar lines to those we have mentioned are in course of execution, and not less than 30,000 kilometres are announced for the complete net-work.

France began later than Germany a similar undertaking, but the work, rapidly carried on, will permit of these new lines being completed in a comparatively short time. Before very long each of the great railways will have, at a short distance from it, a subterranean telegraphic line, which will take the same general course; other conductors will also be established to unite directly the principal towns with these main arteries; and an interruption of telegraphic communications like that of the winter in 1879-1880 will become theoretically impossible.[1]

§ 2 *Submarine Telegraphic Lines.*

In 1839 Mr. O'Shaughnessy connected the two banks of the Hooghly river in India by an insulated metal wire, plunged into the stream. In the next year Wheatstone, whose name is connected with each successive phase of electric telegraphy proposed to connect Dover and Calais by a submarine telegraph cable. This project was not realized till 1850, when the engineer Jacob Brett also placed a copper wire covered with gutta-percha between Cape Gris-Nez and Dover. The cable was broken,[2] but the possibility of submarine

[1] *La Lumière Électrique*, 3rd June, 1882.

[2] "Some messages (about 400) passed, but suddenly the wire remained silent. A fisherman had brought it up in his nets, and hastened to cut off a piece, which he brought triumphantly to Boulogne to show as a singular production, a marine production with golden centre."—W. Huber.

telegraphic communication was demonstrated, and a new cable was definitely established in 1851 across the Channel.

Another fifteen years of trials more or less successful were necessary to solve the problem in all its details; and then the success of laying and working the great Transatlantic cable, which connects Europe with America, between Ireland and Newfoundland, was the beginning of a prodigious development of the universal network. Now the terrestrial globe is traversed not only across continents but in the depths of the sea, with wires carrying everywhere, with

FIG. 420.—Submarine Cable (natural size).

lightning speed, the public and private messages of the whole civilized world.

The conducting wire of a submarine cable is covered with many coatings, the object being to insulate and protect it from destruction, A copper wire 1 or 2 millimetres in diameter, or else a cable formed of five, six, or seven very fine strands, twisted together, constitutes the conductor; the stranded form being preferred, so that in case of accident, some of the wires being broken if one or two of these remain, communication is not interrupted. It is very important that these wires should be completely covered with gutta-

percha; generally four layers being put on, making a total thickness of 3 to 4 millimetres.

Gutta-percha is not only a very good insulator when dry, but becomes even better when exposed to sea-water and extra pressure at the bottom of the sea. At first this envelope was considered enough, but to protect it externally against damage, there is a thick layer of tarred hemp, and this is kept in place and protected by galvanized iron wires twisted round the core. We give here full-sized views of some submarine cables now working. It will be seen that these specimens differ in thickness, but are nearly identical in structure. In the older cables it was thought advisable to place several distinct conductors (Fig. 421) in order to multiply the communications. This

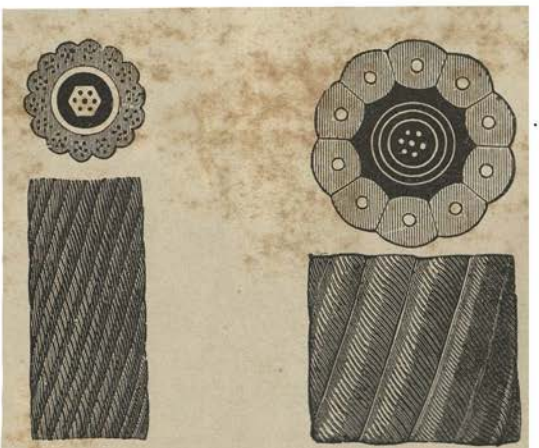

FIG. 421.—Submarine cables; external view and section.

method is now generally abandoned, because of the inconvenience of many wires necessitating considerable volume and weight, which render difficult the operation of laying it, and also the proximity of wires produces induction currents, which interfere with the transmission. Hence it is preferred, if the speed of communication demands it, to establish between the extreme stations several cables, then if any serious accident occurs to one the others would probably be left in working order.

Long cables are usually made of different thicknesses in different parts. Along the coast where the sea is shallow, and the cable exposed to accidents by the agitation of the sea during storms, or by

anchors of ships, or fishermen's tackle, the cable is thickest; the outer coating is formed of wires of large size, covered with hemp sometimes impregnated with Clark's compound of mineral pitch, tar and silica, the object being to increase the resistance to wear proceeding from rubbing against rocks. This is the *shore end* of the cable (Fig. 423). For average depths, the cable is of smaller diameter (*intermediate type*): whilst for the portion intended to be submerged in the open sea, where the water is deepest the lightest

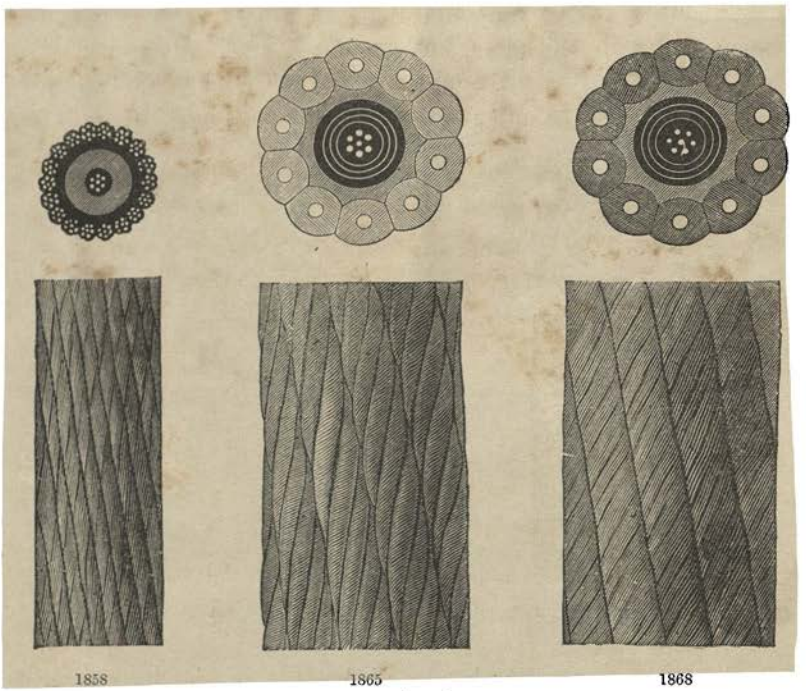

FIG. 422.—Transatlantic cables from Valentia to Newfoundland.

cable (*deep-sea* type) is used, as it has not to withstand the surface agitation, and the work of laying is greatly facilitated by the diminution in weight.

The weight of submarine cables is something enormous. The cable from Dover to Calais, laid in 1851, which is only 25 miles in length, weighed more than 180 tons. Of the Transatlantic cables connecting Valentia and Brest to America the former weighed 865 kilogrammes per kilometre, and the latter 836. The whole weight of

the first is 4,300 tons; and the second nearly 4,000 tons; reckoning only the section comprised between Brest and Saint Pierre. Only one vessel, the *Great Eastern*, was sufficiently large to embark such a cargo. But the inconvenience of such a weight, which diminishes it is true as it becomes immerged, is still very great when

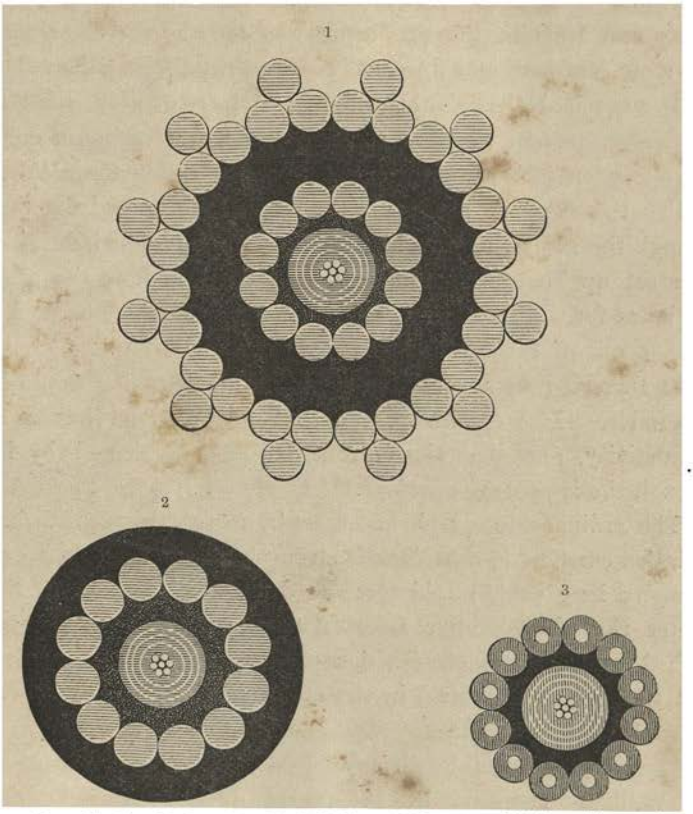

FIG. 423.—Transatlantic cable from Brest to Saint Pierre, laid in 1867; full size section: 1, shore end 2, intermediate type; 3, deep-sea type.

it has to be laid in a great depth of water, and the portion hanging from the ship unrolls to a depth of 2,500 fathoms (4·06 kilometres).

Many people doubted the possibility of transmitting submarine signals to such great distances, as from Europe to America, across the Atlantic. It was not so much the distance that frightened them as the untried experiment of a cable submerged to such enormous depths, in a well-known conducting medium, sea water. How would

the wire act when the electric currents were sent into it? Would the insulation be sufficient? Would the force of the batteries be enough to send the current without disturbance, and without relays, from one end of the immense line to the other? These fears, which were at first only vaguely expressed, appeared for an instant justified when in August, 1858, after some messages exchanged between the United States and Ireland, the apparatus was found to give signals more and more confused, and finally to cease working altogether.

It was found that a cable submerged in sea water changed when an electric current was sent through it into an immense condenser, like a Leyden jar; the electric charge of the conductor in the interior acts on the external conductor, the metal coating, and the sea water, through the insulating envelope of gutta-percha. The induced charges thus set up by the current sent into the line from the apparatus, continued for a certain time, so that it was impossible to send a fresh current till after these had subsided; otherwise the line would seem to be traversed by a continual current, and signalling would become impossible. It was also proved that gutta-percha has a certain conductivity, and that the current becomes weakened by leakage through the insulating envelope.

The ordinary telegraph instruments, moreover, require for their operation currents of considerable strength, and to force such currents through a long cable would necessitate enormous batteries. But the greater the electromotive force of the battery, the more strongly marked does the inductive action of the cable become. Moreover, such strong batteries tend, in the event of any fault, to destroy the cable.

The solution of this difficulty in signalling was first given by Sir William Thomson in 1855. He devised specially delicate receiving instruments, of which more will be said later.

Once the causes were recognized it became possible to combat the effects. Instead of voltaic batteries, a magneto-electric induction apparatus had at first been used, producing currents of much greater strength than the ordinary currents: these were abandoned. Further to neutralize the induced charges, different methods were adopted; one, due to Whitehouse, consisted in sending into the cable alternately currents of opposite sign in order to destroy or neutralize one another. Varley interposed between the transmitter and the

line a condenser with a very large surface (40,000 square feet). Du Moncel describes the action of this condenser in neutralizing the induced currents: "At the moment of contact with the transmitter (simply a current-reversing key) an electric current is sent through the cable to act on the receiver, and this current is positive or negative according to the key of the transmitter pressed. But as soon as the key is raised, communication is established between the condenser and earth, and the electricity condensed is able to flow into the earth on both sides of the line. It happens then that the charge of the contrary sign to that which furnished the first electric current, which acts on the receiver, meets this latter in the cable, and neutralizes it instantaneously, destroying at once the induction effect produced by it in the outer coating of the cable. In this way the cable is brought instantaneously to a neutral state, and becomes immediately susceptible of a new signal."

The following is the system adopted in the Transatlantic line from Brest to Saint Pierre. The telegraphic apparatus is a needle telegraph; the reason for this choice is the extreme sensibility of the galvanometers, the needles of which can oscillate under the action of feeble currents. Nevertheless, to still more increase this sensibility, and to allow the clerks at the receiving station to read the signals without hesitation, Thomson's galvanometers are employed.

"In Sir William Thomson's mirror galvanometer," says Du Moncel, "the sensitive part is a little mirror attached to the small magnetic needle, and this needle is brought back into a fixed position by a controlling magnet. A beam of light is projected on this little mirror and reflected by it on a screen, placed at a distance of eight feet. By this means the slightest movement of the needle and mirror, though imperceptible to the naked eye, is recognized by the position of the projected image, and the motion of this spot of light, to the left or right of a fixed line, indicates the dots or dashes of the Morse alphabet. Thus all the combinations necessary for the interpretation of messages are read on a screen in a dark chamber."

Figures 424 and 425 represent Sir William Thomson's mirror galvanometer and the telegraphic apparatus for the French Transatlantic cable, as used at the station at Brest. The first is a section of Thomson's galvanometer; the second shows the arrangement of

the whole apparatus. In the centre of the bobbin is seen the little circular mirror on the magnetized needle, rendered sensitive by a

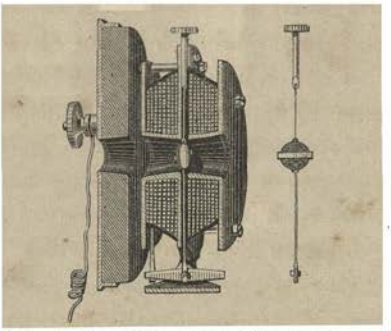

FIG. 424.—Section of Thomson's mirror galvanometer.

magnet E supported on a vertical stem surmounting the galvanometer D. A fine fibre of unspun silk supports the mirror whose movements

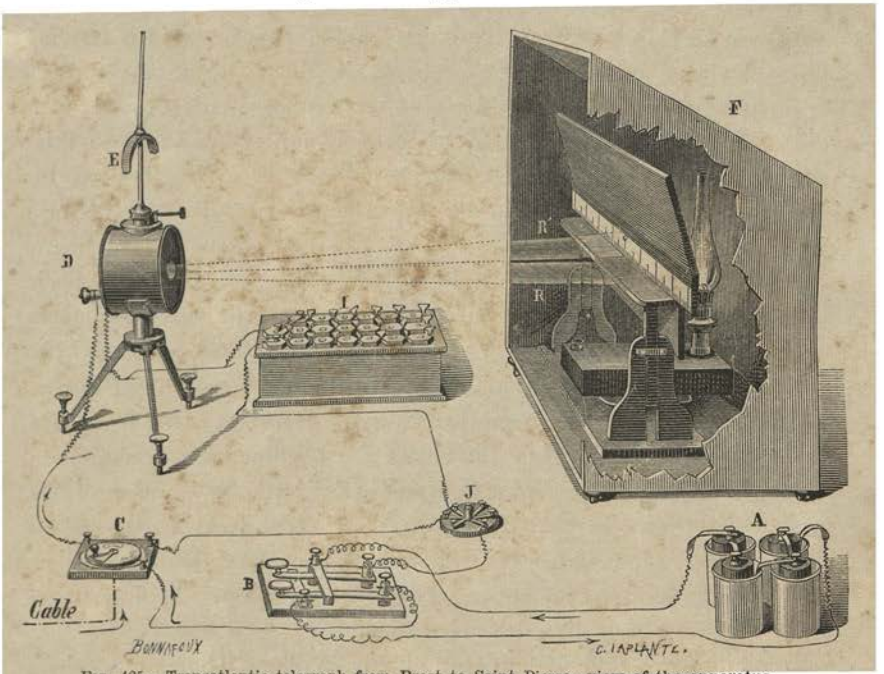

FIG. 425.—Transatlantic telegraph from Brest to Saint Pierre; view of the apparatus.

are damped by a vane suspended underneath. The transmitter B is provided with two keys like Morse keys, to send alternately positive

and negative currents. Negative currents coming along the line to the galvanometer deflect the needle, and therefore the spot of light from the mirror to the left; the positive currents on the other hand all cause deflections to the right. F is a dark chamber inclosing the scales on which are projected the images of the flame from the lamp behind. The luminous beam passes through a hole in the wall of the chamber by the path R, falls on the mirror, and is reflected by R′ to the zero of the scale when the mirror is at rest. When the current transmitted by the cable passes through the galvanometer coils, the mirror oscillates from right to left as we have seen, and the image moves horizontally from one side of zero to the other. A is the battery formed in reality of 20 Daniell cells; at J is the communication of the return wire with earth. C is a switch which the operator must turn into position according to whether he wishes to transmit a message into the cable or to receive one through it from the other end.

As soon as the operator or clerk at the station has received warning that a dispatch is to be transmitted, he puts his switch to the proper position for receiving; then he fixes his eye on the divided scale in the dark chamber, noting all the signs indicated by the successive oscillations of the bright spot, which signals correspond, as we have said, to the conventional vocabulary of the Morse system. There is nothing more to do but translate the message and write it down in ordinary characters.

We said, when stating the numbers indicating the speed of electric impulses through different conductors, that this speed is relatively small in the copper wires of submarine cables. The currents sent by powerful batteries into cables of great length do not instantly rise to the full strength corresponding to the electromotive force and resistance of the circuit; it is only gradually that they arrive at their normal strength. Thus from Valentia to Newfoundland more than three seconds are necessary for the current to attain its maximum strength. These delays, together with the influence of the currents on each other, produce irregularities which have hitherto prevented the use of apparatus like the ordinary Morse sounder or printer, and it has been necessary to have recourse to the more delicate mirror galvanometer.

But Thomson's ingenious galvanometer has the same disadvantage

as all the systems that leave no trace of the message transmitted: the flying signals produced by the motion of the spot of light, which the clerk at the receiving post must seize, so to speak, on the wing besides being the cause of great fatigue to this clerk's eyes, occasion very frequent errors, which necessitate repetitions, and thus bring down the rate of transmission of messages. Thus the Transatlantic cables are scarcely able to send more than sixteen words a minute, that is, forty or fifty messages per hour.

This difficulty has been solved, and again by the inventor of the mirror galvanometer. The newer apparatus is the *siphon*

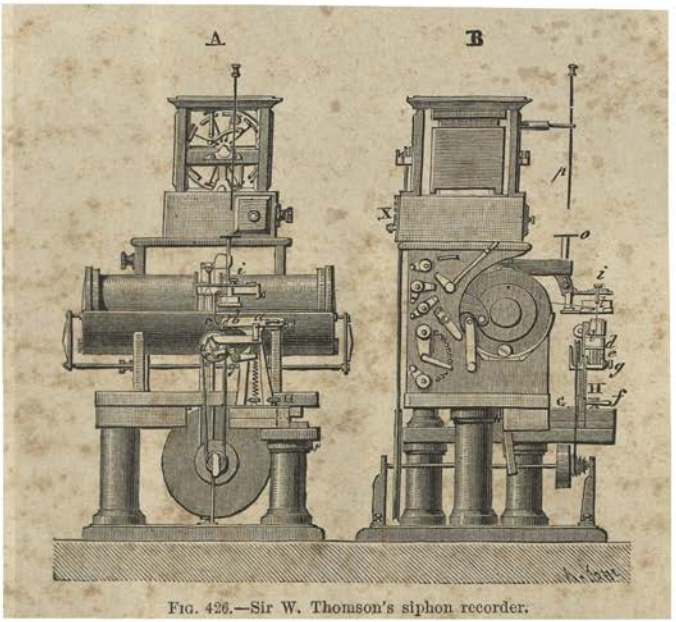

FIG. 426.—Sir W. Thomson's siphon recorder.

recorder (Figs. 426 and 427), which converts the flying signals of the mirror galvanometer into curves drawn on a strip of paper. Sir William Thomson's *siphon recorder* takes its name from the capillary glass tube bent in the form of a siphon, the shortest branch of which is dipped into a little trough full of ink—a solution of aniline blue. The point of the other branch is some millimetres away from a band of paper which is unrolled before it with a uniform motion by clockwork. The ink is constantly electrified by a little influence machine. During the transmission or

reception of a message the siphon tube receives, by means of a silk thread conveniently stretched, motions to the right and left, according to the direction of the currents transmitted; and the ink which escapes from the point is projected on the band of paper, where it traces, by its fine and numerous little drops, the curves, the number and position of which form the characters of the letters or signals.

The glass tube is pulled to and fro by a very light coil, suspended by vertical wires between the two poles of a very powerful electromagnet. According to the direction of the current, which is sent

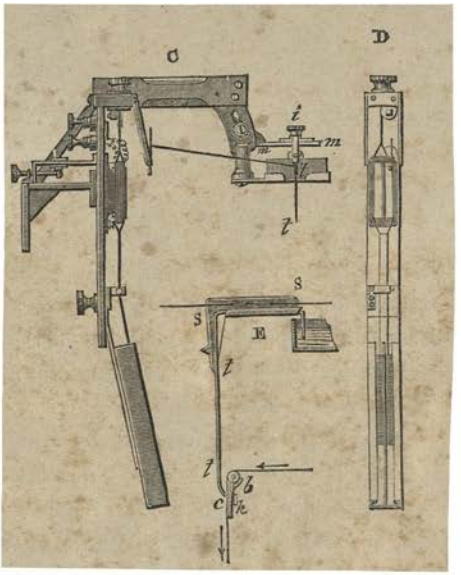

FIG. 427.—Siphon Recorder; details of the suspension.

through the line, and traverses this coil, the latter is moved to the right or left in the magnetic field of the electromagnet, and communicates its movements to the siphon. A special battery excites the electromagnet, and also drives the little influence machine which serves to electrify the aniline ink, at the same time that it draws past it the band of paper. This ingenious little influence machine, known as the *Mouse-mill*, stands, as may be seen in Fig. 426, at the top of the apparatus. In it a number of parallel steel bars are driven round electromagnetically, as in some of the electromotors of Froment; at the same time they act as "carriers" of the induced charges with

which the ink-vessel is electrified. This ingenious device of the electrified siphon gets over all difficulties about friction which would occur if it were attempted to record by the use of an ordinary pen or pencil.

The siphon recorder does not give greater rapidity of transmission than the mirror galvanometer, but it has the great advantage of preserving traces of the messages whether transmitted or received. Mounted in duplex, Thomson's apparatus gives from forty to fifty words a minute; that is more than double what was before obtained from submarine cables.

§ 3.—*Batteries employed in Telegraphy.*

The different systems of telegraphs that we have described may be divided, according to their source of electricity, into two classes; the first worked by a steady voltaic current, and the second, on the magneto-electric principle.

The old batteries of Bunsen and Daniell were the first current generators used for this purpose, and batteries on the Daniell principle (Fig. 428) are still generally employed in England and France, whilst the Bunsen is scarcely ever used except on some American lines. In England the telegraph service is worked by trough batteries, the compartments of which contain sand with a solution of chloride of ammonium, or acidulated water; a plate of amalgamated zinc, and another of copper, are dipped into each compartment. This battery furnishes a feeble current, but it is suitable for working the needle telegraph. In England, Thomson's battery, which is merely a modification of Daniell's cell, has also been employed. Siemens and Halske's batteries (Daniell type modified), 1, Fig. 429, have a high resistance, and are consequently fit for long lines; they are the only ones used by the Indo-European Company on the line between London and Teheran.

The Minotto cell (2, 3, Fig. 429) being very portable, since it contains no liquid (replaced by damp sawdust), is exclusively employed in distant stations in India.

Batteries of the Daniell type are easy to keep in order. It is necessary from time to time to pour in fresh liquid, to repair

the losses by evaporation, either in the jar containing acidulated water, or in the porous pot with the solution of sulphate of copper; also to keep a sufficient quantity of crystals of sulphate resting on

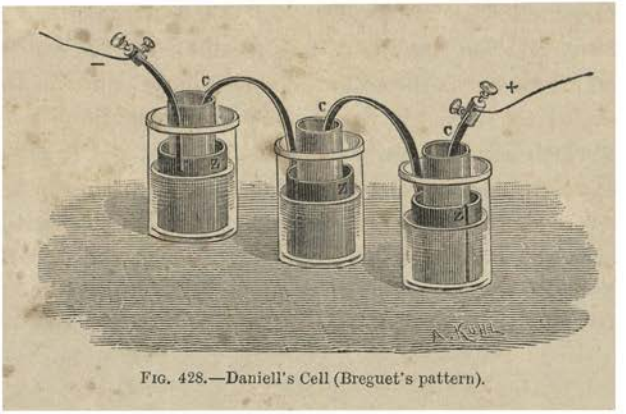

FIG. 428.—Daniell's Cell (Breguet's pattern).

the shelf. Lastly, the deposits on the sides must be cleaned away now and then, and the zinc plates replaced when the amalgamation is worn through. The constancy of the current in a Daniell cell,

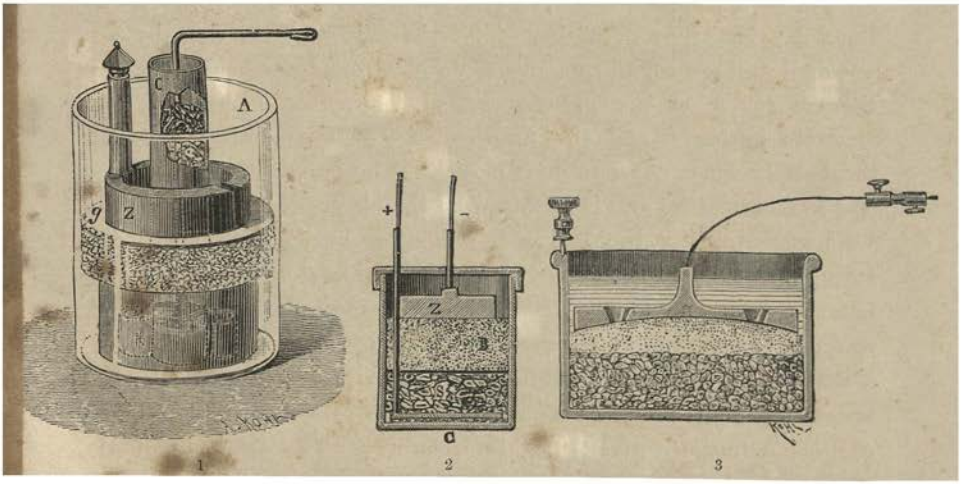

FIG. 429.—Cells employed in Telegraphy: 1, Siemens-Halske; 2, Minotto; 3, modification of Minotto.

which has worked for three months without repair on a much used line, as long as that from Paris to Berlin, shows it to be a good source of electricity. The number of Daniell cells employed for

distances of 100, 200, and 400 kilometres, is 30, 50, and 70 respectively.

In France the Callaud cell is used, also the Leclanché, Maiche, and in Germany that of Meidinger. We have described most of these batteries. The success of any kind of battery must largely depend on whether it is suited to the particular telegraphic apparatus it is intended to work. It is necessary to distinguish between line batteries, which send currents to great distances, and local batteries, which are only used for the apparatus at the station; in the latter the circuit is very short and, as they have not to furnish electricity for the line, they consist only of a small number of cells, the whole electromotive force of which is naturally much less than that of the line batteries.

§—4. *Bells.*

We pointed out the use of bells when describing telegraphic apparatus, without entering into any details of their mechanism.

The most common form of electric bell used on French telegraph lines is that shown in Fig. 430. The current entering by the terminal A, flows round the coils of an electro-magnet, and thence by the contact B on the hammer BM and a spring R, through the screw to button *b* and the terminal D which communicates with the battery when the circuit is closed. The handle of the hammer acts as an armature and is attracted by the electro-magnet poles, thus the hammer strikes the bell, but in doing so breaks contact with the spring R at B; then the current is interrupted, and the handle of the hammer being no longer attracted by the electro-magnet falls back again on the spring; this completes the circuit again and gives rise to a new current and so on, whilst the circuit passes through the bell apparatus. This produces a series of blows in rapid succession, hence the name *trembler* given to this apparatus. The principle of the mechanism is due to Wagner, but a Belgian electrician, Lippens, first applied it to bells. The ordinary system of trembling bells was invented in 1850 by John Mirand.

When a prolonged and louder sound is wanted, a detent or escapement is arranged in the mechanism of the trembler, which introduces a local battery into the bell circuit. This is the plan

in Aubine's bell (Fig. 431). A bent lever is held against the

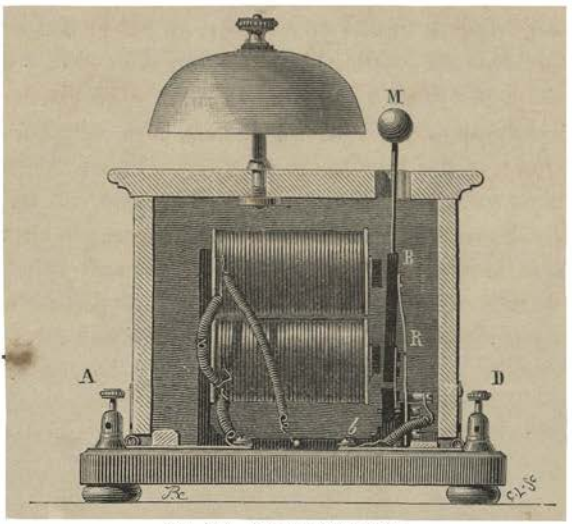

FIG. 430.—Breguet's Trembler.

handle of the hammer on a lateral tooth, when the bell is put in action by the feeble current from the line, the hammer is

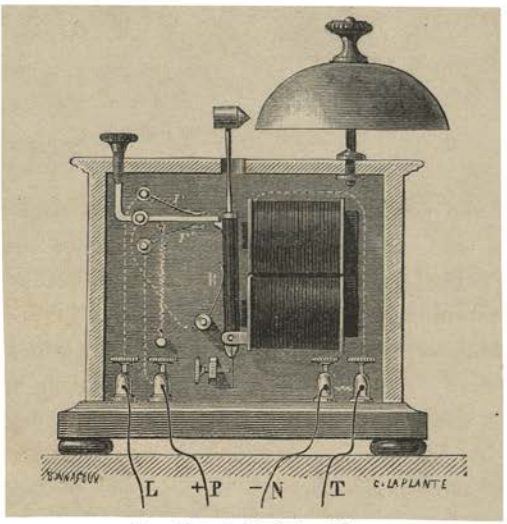

FIG. 431.—Aubine's Trembler.

attracted by the electro-magnet, and the lever is pulled down to the

spring r', having broken contact with the spring r. Thus the line circuit L T is broken, whilst that of the local battery P N is completed. The bell is kept ringing by this stronger current until the clerk replaces the detent or lever by pressing the button on the end of the lever at the top of the box. Such a bell is called a "continuous ringer."

An important application of electric bells is in mines or collieries, where the lives of the miners are at stake. The presence of fire-damp, when in sufficient quantity to be dangerous, can be indicated automatically by the aid of an apparatus in which electric communication is established between a battery and bells. If two gases of unequal density are separated by a porous membrane, they will pass through the membrane at different rates. At the end of a certain time they will have mixed; but as the lightest

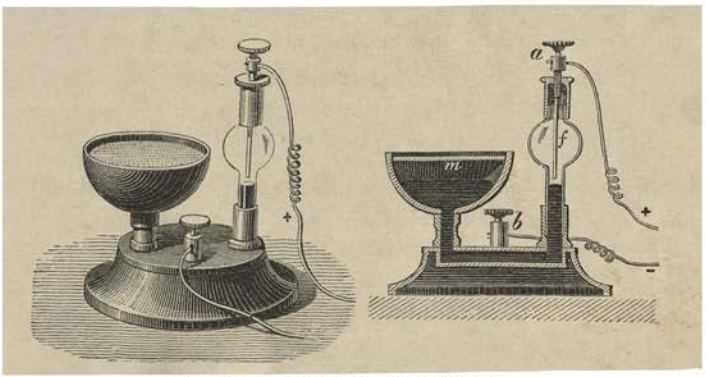

FIG. 432.—Ansell's Fire-damp Indicator.

gas traverses the porous partition more quickly than the other, the result will be an increase of pressure in the space occupied by the latter. This is utilized in Ansell's *Fire-damp Indicator* (Fig. 432).

A tube is employed with one branch terminating in a hemispherical funnel or vase closed by a porous plate m. The tube contains mercury to the same level in each branch under ordinary circumstances, that is, if the air in the mine is pure. But if carburetted hydrogen becomes disengaged round the apparatus, the explosive gas penetrates through the porous plate, increases the pressure in this branch of the tube, and pushes the mercury up in the other branch. When the mercury touches the metal rod f the circuit is completed between the positive and negative terminals a, b, of a

battery. The current passes, rings a bell, or produces some other telegraphic signal, either in the mine or outside it. The same apparatus may be used to show the presence of a gas, such as carbonic acid, or sulphuretted hydrogen, denser than air. It is then needful to establish contact in the part of the tube that is situated under the porous plate.

§ 5.—*Lightning Protectors.*

The superiority of the electric over the old aërial telegraph is due principally to the rapidity with which messages can be transmitted whatever be the distance between the extreme stations; a few seconds suffice for this docile agent to pass over thousands of miles or kilometres. But that is not the only reason for rejecting, as superannuated, a method of correspondence which appeared a marvel of swiftness forty years ago. Constancy is needed. Almost perfect continuity of working is obtained by carefully maintaining the batteries, line, transmitting and receiving mechanisms, in good condition. Chappe's optical telegraph only worked by day, and in fine weather. Such is not the case with the electric telegraph, which can work the whole year, day and night, except when the transmission of electric currents is hindered. During thunderstorms the line wires become affected, causing disturbances in messages coming from stations far distant from the seat of the storm. Auroras produce similar effects and irregularities for which no sure means of remedy is at present known. These perturbations are sometimes sufficient to cause damage either along the line or to the apparatus at the stations. During violent storms lightning may shatter the posts and the porcelain insulators; or the magnets and needles may be demagnetized. On the other hand the coils surrounding the cores of electro-magnets may become under these circumstances fused, or short-circuited, thus rendering them useless. For this there is no other remedy but careful watching of the line and apparatus at the stations, with repeated tests of their proper working, particularly in stormy weather, or when auroras appear. In case of damage the objects broken or spoiled must be replaced; but all that is now foreseen, and well-organized lines possess, in their important offices, the indispensable pieces in duplicate; and therefore interruption lasts only a short

time. There is one danger that can be effectively prevented, namely that which threatens the security and life of telegraph clerks. In the early days of electric telegraphy large sparks burst between metal objects scattered the pieces about, and wounded or killed people who happened to be in the path of the spark. Every station is now furnished with a very simple piece of apparatus to make the atmospheric electricity flow to earth, and in this way protect at the same time the clerks and telegraph instruments. These *lightning protectors* are various in principle and form.

Breguet's *lightning protector*, Fig. 433, is very simple. It consists essentially of two metal plates with teeth opposite one another, of a

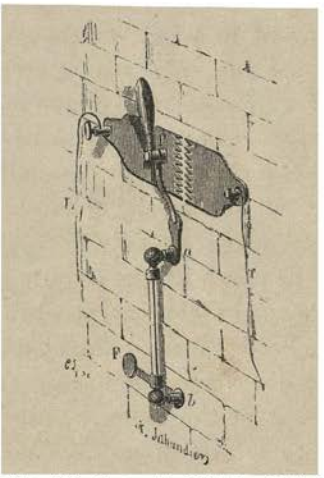

FIG. 433.—Breguet's Lightning Protector.

glass tube containing a very fine iron wire joining electrically the terminals *a* and *b*, and of a switch F. When F is in the position shown in the figure the line-current passes from L to F, and thence into the apparatus. The electricity from the battery not being of sufficiently high electromotive force to escape across by the points on the plates, it continues on its ordinary path; but atmospheric electricity sparks across the points, and thence through the wire T to earth.

In the case of a very slight storm this means of escape may be insufficient, and in this case the electricity traverses the wire which it may heat and even melt. This fusion of the wire breaks off communication with the office, and the storm electricity escapes to

earth. If a storm is expected the switch is placed so as to connect the plates directly, and all communication with the office is stopped.

Fig. 434 shows another lightning protector with a similar arrangement of points, and based on the different ways in which electricity behaves, according as it is derived from batteries or is due to atmospheric disturbances. The switch is provided with three contact pieces. When the middle contact is on the boss *d*, as is shown in the figure, the current in the line wire flows directly into the office; it is easy to trace by the dotted lines the electric connections of the various parts of the apparatus. From the terminal L of the line wire the current enters the switch, and thence to the terminal F of

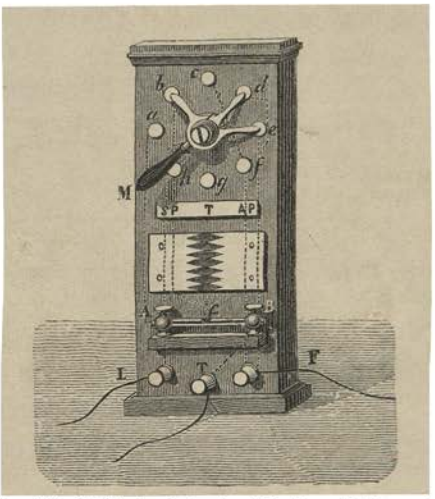

FIG. 434.—Lightning Protector of the French Telegraph.

the office; it does not pass through the wire *f*. In case of a storm the middle contact is placed on the boss *b*, then the current traverses the pointed plates and the wire before entering the office. Again, if it is a violent storm the switch handle is placed opposite the letter T, the middle contact being on the boss *c*. All the electric currents directly escape to earth without having any communication with the apparatus in the office, which is thus protected from any danger.

Bianchi's lightning protector also depends on the action of points. In the case of atmospheric electricity coming from the line, this electricity escapes by points arranged inside a glass globe around a metal ball, which is connected permanently to earth through a metal

ring. If a vacuum is made in the globe the discharge occurs more easily but this precaution is unnecessary.

The lightning protectors shown in Figures 435 and 436 do not depend on metallic points but only on the difference of electro-motive force between electricity in ordinary line-currents and atmospheric or storm electricity. Whilst the former is stopped by an insulating sheet and passes on to the instruments, the other escapes through the larger conductor placed to receive it, in spite of the intervening insulating body. Thus it can escape to earth without causing any disturbance or damage in the office. The *Siemens and Halske lightning protector* (Fig. 435) consists of a base plate in connection with the earth; above it, as near as possible, but without being in metallic

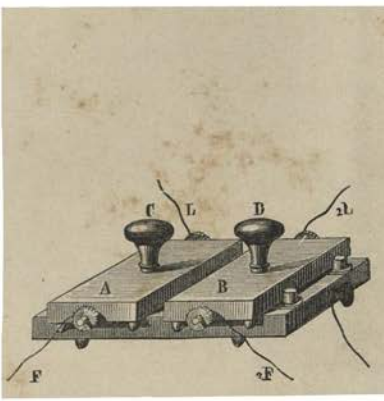

FIG. 435.—The Siemens and Halske Lightning Protector.

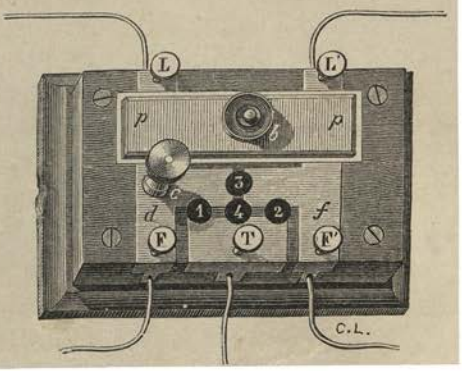

FIG. 436.—Belgian Lightning Protector.

contact, are two smaller plates A, B, attached at one end to the line wires L, L_2, at the other end to the instruments by the wires F, F_2. Voltaic currents have not sufficient electromotive force to overcome the resistance between the conductors and the earth plate; but in the case of storms the atmospheric electricity takes the shorter way and the instruments are preserved.

The lightning protector used on the Belgian lines (Fig. 436) consists of metal plates *pp*, *df*, separated by a thin sheet of insulating paper. The line wires of the two neighbouring stations are attached on the left and on the right at L and L′ and those from the instruments in the office at F and F′; T is connected with the button B and with earth. Four holes, 1, 2, 3, 4, bored in the block of wood

which carries the plates, are made to fit a metal plug C, which connects the various parts of the lightning protector. During the ordinary state of affairs, the plug is kept in the position shown in the figure; then the neighbouring offices are in connection with the instruments in the telegraph office; correspondence is open on both sides. When a storm is announced from the right, the plug is placed in hole 2, the atmospheric electricity then passes to the earth through the plate and wire T. If the disturbance is from the left, the plug is placed in hole 1. The plug is placed in hole 4 when there is a storm on both lines. Hole 3 is used to establish direct communication between the two lines, and thus this apparatus serves the double purpose of lightning protector and switch. In closing this paragraph we will describe one cause of disturbance which is perhaps less serious than storms, and produces less serious irregularities on the lines: it is the bad state of communication between the instruments and earth.[1] One of our chief telegraphic engineers says on this subject:

"When several lines run to the same station one single conductor usually serves to put the negative pole of the line battery and all the receivers of the station into communication with the earth. Under these conditions, a bad earth connection can produce very troublesome disturbances in the correspondence. If the office is receiving, and if all the manipulators are in the position for receiving, the current flows as usual from the wire in connection with the sending manipulator through the corresponding receiver, but, instead of passing entirely to earth it returns, or at least a part of it, to flow through all the other receivers and line wires attached to that office, consequently all the receivers at that station work at the same time. Similarly, if the earth connection is very bad, the return currents preserve sufficient intensity to start the receivers at the sending office.

[1] On the introduction of telegraphy it was believed necessary, in order to close the circuit, to place two different wires between the two stations; the second acting as the return wire. But Steinheil in 1837 proved that the second wire was not necessary to complete the circuit, but that the earth could take the place of the return wire. Accordingly each instrument, transmitter and receiver, should be put to earth, that is to say, connected with the earth by means of a special wire, some yards long, buried in damp earth; usually the contact is made more complete by attaching the earth wires to metallic sheets of a convenient size, a yard square, for example, so that the electric communication with the earth is made at a great number of points.

When an office with a bad earth connection is sending, the flow of negative electricity from the battery, meeting with too great a resistance at its earth, works the receivers in the office, passes along several line wires and influences the receivers in the distant office. With a very bad earth connection it may happen that all the receivers of the two stations work at the same time."

A lightning protector much used in the British Post Office consists of two thick brass disks separated by a sheet of mica, perforated with several holes; the opposing brass surfaces are platinised. The line and instruments are connected to the upper disk and the lower disk is earthed.

§ 6.—*The Universal Telegraphic Network.*

We need scarcely point out the importance of the electric telegraph in connection with private, public or international affairs. This application of one branch of physics, which has made the greatest progress during the present century, is such a striking conquest of the human mind over time and distance, that no one can calculate its important influence. Its origin was the restraint placed upon public or ministerial correspondence, upon diplomatic despatches—this caused its development; but it has also been found necessary to institute a service for private messages. The use of the telegraph has extended enormously since this was done, and is still daily increasing, in proportion to the number of stations opened for work, so that speaking only of France, twenty-seven years ago there were seventeen telegraph offices sending annually about 9,000 messages, whilst in 1883 there were 3,500 offices sending more than six million telegrams per annum.

The telegraphic despatch is not only convenient for family relations or friends, but above all for business matters, commerce, industry, and stock speculations. Diplomacy, war, public works, government, politics, and the police continually use it. In a more calm and elevated region, that of science, it renders the greatest service, by supplying astronomers with the means of accurately determining longitude, and of signalling to all other observatories the discoveries of new stars, comets or planets; thus saving some weeks in verifying and registering their discoveries.

In meteorology the telegraphic service announces coming storms, the rising of water-courses, gives warning of storms at ports, and thus supplies navigation with valuable information which has already done much to diminish the risks of ships and their cargoes.

This enumeration of the services rendered by telegraphy is very incomplete; but the best means of showing its enormous importance is to give some figures relating to the actual working of the network of air-lines and submarine cables which to-day cover the whole earth.

The development of lines has reached no less than two and a quarter million of miles, that is, ninety times the length of the circumference of the earth. Of this total 120,000 miles are submarine lines, consisting of 1,064 cables of very unequal lengths.

In Europe, seventeen years ago, the air-lines measured 220,000 miles, with a total length of wire of 430,000 miles; at the end of 1877 the European system had a length of 279,680 miles of telegraph lines and 745,000 miles of wire. France then possessed 27,300 miles of lines, and 76,500 miles of wire; at the end of 1880 the length of the French telegraph lines measured 36,757 miles, whilst in 1851 the length of wires only measured 1,243 miles.

The various divisions of the world, possessed, at the end of 1889, telegraph land-lines of the following lengths, which do not include the numerous lines made for the special use of the railways:

Europe	1,002,794	kilometres.
North America	723,477	„
South and Central America ...	62,517	„
Australasia	71,717	„
Asia	128,928	„
Africa	12,969	„

The number of telegrams sent has increased in an enormous proportion. To give some idea of the activity of the correspondence in manufacturing countries, we will quote England. In the course of the year 1870, 10,200,000 telegrams were sent along its wires—203,600 per week. Mr. W. Huber, to whom we are indebted for these statistics, told us that on July 18th, 1870, the day when the declaration of war between France and Prussia was known in London, 20,592 telegrams passed through the central office alone. The Indian telegraph service

in 1871 sent 33,000 messages. In spite of the high tariff on the trans-Atlantic cables, 240,000 cablegrams were sent across the ocean in a single year.

In the United States, where the lines, on the 1st of January, 1881, were 169,121 miles long, and the wires 310,000 miles, the number of telegrams sent in 1880 exceeded 35,000,000. The wires used exclusively by railways are not included in these figures.

The above statistics suffice to give one an idea of the extent that this rapid correspondence has assumed in various parts of the globe; but they may be supplemented by an examination of the actual state of the universal network shown in Plate XII. This plate is reproduced from a large chart in the possession of the Eastern Telegraph Company, upon which are marked all the submarine cables, and all the principal overland routes of telegraphic communication down to the month of September, 1890.

The telegraph lines joining the various European and American countries cannot be shown without complication. Those only appear which act as trunk lines and connect the continents by means of submarine telegraph cables. Europe is in direct communication with North America by ten cables, of which six start from Ireland, two from Brest, and two from Cornwall, they end in Trinity Bay, Newfoundland, at Saint Pierre, Miquelon, in the territory of the United States, and in Nova Scotia. South America is also connected with Europe by submarine cables which go by way of Madeira, with branches along the west coast of Africa, and Cape de Verde Isles, and end near the most easterly point of America, at Pernambuco (Brazil).

At the present time India is in telegraphic communication with Europe by two submarine cables; both pass along the Red Sea, then, by the Mediterranean, they split into several branches, which go to Sicily, Italy, and France, and then to England, coasting along Portugal, whence they gain the south-west point of Great Britain by the Atlantic. Other submarine cables are carried from India up the Persian Gulf, from the head of which they are connected by air-lines with the European telegraph systems, whence connection is made with England. Again Australia is in communication with the Indian system; thus a message may be sent direct from Sydney to New York or Boston and thence across the American continent to San Francisco on the shores of the Pacific Ocean, 270° longitude, and an effective

PLATE XII.—MAP OF THE WORLD SHOWING ALL THE CABLE ROUTES AND PRINCIPAL LAND LINES, CORRECTED TO SEPTEMBER 1866.

distance of more than 18,600 miles is crossed by electric signals in less than an hour. Quite recently a chain of cables has been laid around the coasts of the African continent, connecting all the principal ports.

We are indebted to Mr. Huber for the following fact which will suffice to show the rapidity of electric correspondence :—

"On the 12th of November, 1882, a banquet was held in London and Adelaide at the same time by those interested in that great line of 35,852 kilometres, 28 kilometres being overland line (the trans-Australian line). In London a piece of telegraphic apparatus was placed behind the president's chair. At the opening of the banquet, a congratulatory message was sent to Australia. At the end of the banquet the reply, ending with *Hurrah !* arrived from Adelaide." [1]

An examination of the chart shows that a gap still exists in the complete encircling of the globe with cables.

America and Asia are not yet directly connected; but four lines, two of which are completely submarine, are projected. The Pacific Ocean will doubtless soon be traversed by the electric currrent, as the Atlantic has been for 22 years. Now messages arrive in Paris and London from all the remotest points of the earth, and we read in the evening papers the principal events that have occurred during the day (and also at night) in the five parts of the world. One can only contemplate in imagination the future effect of these continuous communications on the political, commercial, and industrial relations of nations, in a word, on the progress of civilization.

[1] *Nature* quotes the following instances of rapid telegraphy over long distances : The day of the opening of the Melbourne Exhibition a telegram was addressed to the Queen of England by the Commissioner-General, Lord Normanby, despatched at 12.50 P.M. ; this telegram arrived in London at 3.48 P.M. The difference in time between the two places owing to difference in longitude is three hours six minutes. Thus the message only took thirty-eight minutes in passing over a distance of 10,000 miles. The telegram consisted of sixty-six words. Another example of rapid transmission is that of a despatch from London to Sydney sent in an hour and twenty minutes, but which only took thirty-five seconds in being sent from Singapore to Sydney, *i.e.*, 5,070 miles.

CHAPTER VII.

THE TELEPHONE AND MICROPHONE.

§ 1.—*The Origin and Invention of the Telephone.*

UNDER the name of telephone are included all systems for the transmission of sound to a distance, whether words or acoustic signals. But since the invention of the wonderful instruments that we shall describe in this chapter the name telephone has been mostly restricted to instruments for the transmission of sounds by means of electricity. This mode of transmission exceeds sound waves in velocity by possessing that enormous speed of propagation that we have seen to belong to electricity. To-day the telephone rivals the electric telegraph in point of speed and even approaches it in the magnitude of the distances traversed.

The first ideas of this recent invention date back to 1837, when an American physicist, Page, observed that at the moment when substances are magnetized they emit a sound. On bringing a flat spiral carrying a current between the poles of a horse-shoe magnet, he heard a musical sound. De La Rive, Gassiot and Marrian observed the same phenomenon in a bar of soft iron placed in a helix, at the moment when the helix is traversed by a current. By causing the current to pass with very rapid intermittences, the sound is more intense, but is feebler if a bar of tempered steel is used instead of soft iron.

The study of sounds produced by electricity remained for a long time in the domain of theory; physicists in carefully studying the circumstances in which these phenomena were produced endeavoured mainly to explain their causes by the molecular movements resulting from the orientation of these elementary magnets.

According to De La Rive, the discontinuous current which traverses the coils of the helix tends to place the molecules of the bar which is subjected to magnetization in longitudinal lines, and each time the current is broken the molecules by virtue of their elasticity vibrate in resuming their positions of equilibrium. The greater freedom of movement that they have in soft iron explains the greater intensity of the sound produced in that metal than that which is heard with a bar of tempered steel.

Whatever may be the value of these proposed theories regarding this interesting question of molecular physics, the facts recently brought to light in the invention of the telephone have acquired such an importance, and their applications have made such developments, that all details relating to them are of interest.

The first sounds that were transmitted to a distance by electricity were merely small tinkling sounds, one of which was heard in the iron bar each time it was magnetized or demagnetized. Wertheim proved that the pitch of the note was the same as that emitted by the bar when struck at the end—proving that magnetization set up a longitudinal vibration. The first person to discover that electric currents sent out by a proper electrical transmitter could impose upon an iron mass vibrations other than that of the bar itself was Philipp Reis. In the telephone invented in 1860 by Reis this principle was applied. His transmitter was to transmit the sounds electrically to the distant receivers, which emitted all such sounds as were thus imposed upon it. The problem of making a transmitter to work his receiver was imperfectly solved by Reis, though he succeeded in transmitting both words and music.

Sixteen years later Prof. Graham Bell invented the magneto-electric method of transmission and greatly improved the receiving instrument.

2. *Early Telephones.*

Every telephone consists of two distinct parts, connected together by a line wire, namely a *transmitter* to send, and a *receiver* to repeat aloud the message. Fig. 437 represents the transmitter and receiver of Reis's telephone. K is a hollow box intended to receive the vibrations which enter by the tube T, serving as a mouthpiece

into which the operator speaks or sings. At the top of the box is placed a very tightly stretched diaphragm or tympanum of bladder, which of course vibrates in correspondence with all sounds that are imparted to it. This diaphragm carries at its centre a small disk of platinum O, stuck to its surface; a bent lever, *c b a*, has its two arms *a* and *c* metallically connected through a side signalling apparatus consisting of a key *t* and an electromagnet A, to the line wire. The positive pole of a battery is fastened to the screw *z* in connection with the platinum disc O. This signalling apparatus,

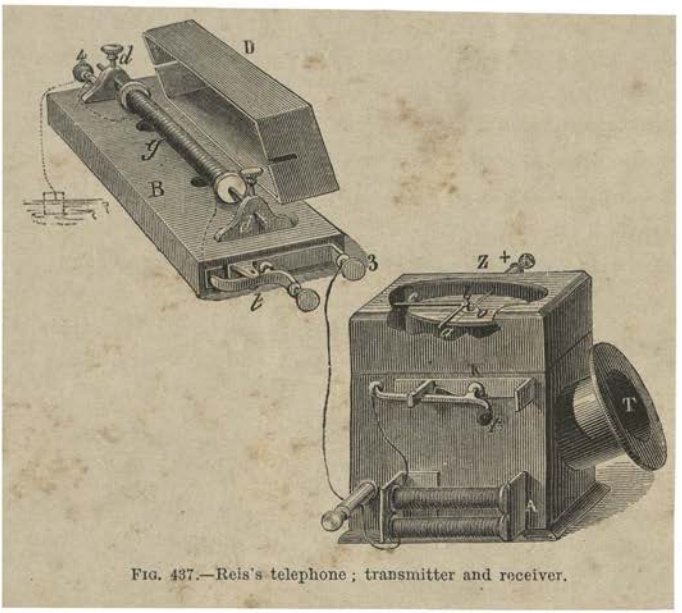

FIG. 437.—Reis's telephone; transmitter and receiver.

which corresponds to the call-bell so universally attached to modern telephones, is no part of the telephone itself, but merely serves for call signals. There was no such signal call on Reis's first telephones. The point *b* rests lightly on the platinum disk, and when the current flows in the line it passes through the loose contact between the point and the disk, and is therefore subjected to disturbance when the membrane vibrates. One then sees that all the vibrations of the membrane produce a series of disturbances of the current, of which the number will be identical with that of the sound which causes it to move and will vary with it. Reis's way of putting it

was that the transmitter was to open or close the circuit in proportion to the vibrations.

Let us now see how the receiver works. It consists essentially of a steel needle *d d*, the size of a knitting-needle, supported by two bridges on a sounding box B. An electromagnet coil *g* surrounds the needle for the greater part of its length, and the wire of this coil is connected to the earth by terminal 4, and to line by terminal 3, thus completing the circuit. The key *t* is used as in the transmitter for the signal-call between the two stations, and is no part of the telephone proper. As soon as the transmitter works, the perturbations of the current determined by the vibrations of the membrane affect the coil of the receiver, and the particles of steel in the wire *d d* under their influence are set into vibration, as in the experiments of Page and De la Rive. The notes of a musical air played before the mouthpiece of the transmitter are thus reproduced with their relative intensity and pitch. To increase the sound transmitted, the sounding-box of the receiver has a kind of lid D which should be pressed by the listener against the vibrating wire. The sounds transmitted by Reis's telephone are rather weak and muffled. Moreover they do not perfectly preserve the timbre peculiar to the sounds imparted to the transmitter. Nevertheless they permitted differences of quality to be observed. Professor Bohn says that in the early experiments in 1864 the son of Privy Councillor Jhering of Giessen was found to be a better speaker through the telephone than most other persons, and that it was easy to distinguish the voice of the boy from that of a girl. Reis himself states that, when chords struck on the piano were transmitted, a person having a musical ear could in the majority of cases distinguish the various notes in the chord. These observations are not without importance seeing that it has been so often stated, in the teeth of obvious facts, that Reis's telephone could transmit pitch only and not quality. Reis also devised a second type of receiver in which an electromagnet was made to attract an elastically mounted armature of iron. In subsequent years Yeates and Van der Weyde endeavoured to improve the instrument. The latter strengthened the vibrations in the transmitter by making the interior sides of his box curved so as to reflect them, and in the receiver by using in the coil several iron wires instead of one. The sounds thus become fuller and stronger.

Messrs. Cecil and Leonard Wray also endeavoured about the year 1876 to improve Reis's apparatus: they abolished the loose contact between the two pieces of hard metal, and substituted there for an arrangement of mercury cups. This supposed improvement entirely destroyed the power of the instrument, and prevented the natural microphonic action of the loose contact from taking up the small vibrations or small variations in the larger vibrations. Wray's receiver also differs from Reis's by being formed of two coils each surrounding a core of iron; the two cores are held in supports; they are, like the coils, in a line with each other and their neighbouring ends are very near but do not touch, and work by mutual attraction.

The fundamental ideas of Reis were based upon the construction of the human ear. He had set out with the direct intention of transmitting speech electrically, as he states in the opening sentence of his first paper on the subject, communicated in October, 1861, to the Physical Society of Frankfort-on-the-Maine. But he was at first baffled by the difficulty of finding a form of apparatus that could respond to all the various tones that are simultaneously used in speech. At last he saw that the human ear itself solved the problem, and furnished a sort of type of the requisite mechanism. His first experimental transmitter was therefore an *electric ear*. It is still preserved in the Patent Museum in Berlin. It was carved in wood, and had a tubular passage leading down to a diaphragm or tympanum of membrane, behind which came the electric mechanism consisting of a little lever of platinum making contact against a platinum-tipped spring. He subsequently improved the instrument, devising many forms of transmitter of which Fig. 437 is one.

Strange to say, although Reis's telephones were sent all over the world, this brilliant invention passed into almost utter oblivion. Much misconception at one time prevailed about the nature of Reis's invention, and attempts were made to stigmatize it as a mere musical toy. Persons were found, in particular lawyers who were paid for what they said, to declare that Reis's apparatus never did and never would transmit speech, and ingenious theories were proposed to prove that it could not. One favourite device of these interested persons was to describe Reis's instrument as a "tone-telephone," a name Reis never used, and to classify it not with other telephones, but with the very different class of instruments now known as harmonic

telegraphs. In this class of instruments tuned bars or reeds are employed to transmit special fixed musical notes. Instruments of this kind have been devised by Elisha Gray and Graham Bell. They are mentioned in the chapter on Telegraphs.

§ 2.—*Magneto-Telephones.*

In the early instruments that we have described the function of the transmitter was merely to modify or perturb (in correspondence with the vibrations of the wire) a current generated in a battery. If they did not speak as well as the modern instruments do, it was partly because of a want of sensitiveness in the receiving apparatus, partly because of mechanical imperfections which prevented the correspondence between the vibrations of the voice and the fluctuations impressed upon the current from being perfectly observed. Reis himself found that consonants were more perfectly transmitted than vowels by his apparatus, and sought to investigate the phenomena and to remedy it.

When in 1876 Graham Bell approached the question, he sought a different solution to the electrical part of the problem, though like Philipp Reis he started from the human ear as a model. He proposed to make the vibrations of the voices themselves generate the electric currents by applying the diaphragm of the transmitter to operate a magneto-electric induction apparatus. He thus invented the Magneto-telephone. Ten years have scarcely elapsed since that invention, which the great British physicist, Sir W. Thomson, characterized from its commencement as the marvel of marvels; and although we have largely ceased to use Graham Bell's actual method of transmitting, the impetus which his invention gave to the subject of the telephone has spread everywhere; already a score of other applications have arisen for Bell's form of apparatus showing what good fruit an original idea always bears in the field of scientific research.

In 1876, at the Centennial Exhibition in Philadelphia, two telephones were shown, one of them that of Graham Bell, the other devised by Elisha Gray. There appears to be some dispute about the exact patterns of instrument with which speech was first obtained by

Graham Bell, but we will give the account which the inventor has himself given of the first decisive experiment which was made with the transmitting instrument shown in Fig. 438.

But let us commence by describing the apparatus itself. M is an electromagnet excited by the current from a battery, the poles of which are close to a membrane stretched on a disk of iron; at the centre of the membrane is fixed an armature consisting of a clock-spring about the size of the thumb-nail; the screws *v*, *v*, *v*, attached to the opening E in the form of a funnel or speaking-tube, permit of the regulation of the tension on the membrane. Also the distance of the poles of the electromagnet from the armature can be adjusted by means of a screw attached at the back. The receiver was sometimes a similar

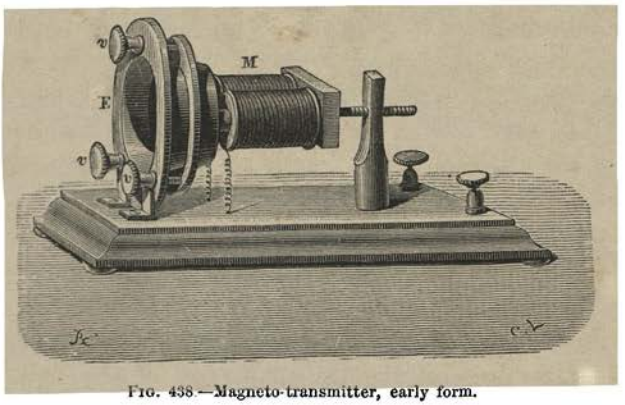

FIG. 438.—Magneto-transmitter, early form.

apparatus, but sometimes one resembling Fig. 439 was shown. On speaking into the opening, the vibrations of the air are imparted to the membrane as in Reis's instruments; but now comes in the magneto-induction principle. The bit of iron used as an armature, oscillating in front of the poles of the electromagnet, sets up in the coil a series of induced currents, which are superimposed on any current previously flowing therein: these currents transmitted to the receiver by the line-wire react on the electromagnet in that apparatus: the armature and membrane at the distant end thus reproduce the vibrating movements and emit corresponding sounds. We here take up Bell's own narrative recounting how with an apparatus so arranged he obtained, with the assistance of one of his friends, Mr. Thomas Watson, telephonic transmissions which proved

to him that he was on the right track. "I remember," he says,[1] "an experiment made with this telephone which at the time gave me great satisfaction and delight. One of the telephones was placed in my lecture-room in the Boston University, the other in the basement of the adjoining building. One of my students repaired to the distant telephone to observe the effects of articulate speech, while I uttered the sentence: 'Do you understand what I say?' into the telephone placed in the lecture-room. To my delight an answer was returned through the instrument itself, articulate sounds proceeding from the steel spring attached to the membrane, and I heard the sentence, 'Yes, I understand you perfectly.' It is a mistake, however, to suppose that the articulation was by any means perfect,

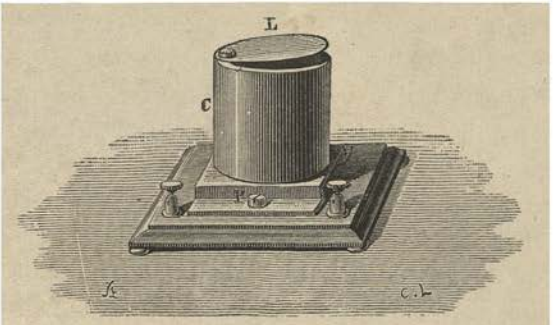

FIG. 439.—Magneto-telephone; early receiver.

and expectancy no doubt had a great deal to do with my recognition of the sentence; still the articulation was there, and I recognized the fact that the indistinctness was entirely due to the imperfectness of the instrument. I will not trouble you by detailing all the various stages through which the apparatus passed, but shall merely say that after a time I produced the form of instrument shown in Fig. 439,[2] which served very well as a receiving telephone. In this condition my invention was exhibited at the Centennial Exhibition in Philadelphia."

In this apparatus, which was shown by Sir William Thomson at Glasgow in the autumn of 1876, there is substituted, for the membrane

[1] *Journal of the Society of Telegraph Engineers*, October 31, 1877.

[2] [The numbers here are of course changed to correspond to the numbering of the cuts in this work.—ED.]

of paper or skin, a thin iron membrane, attached at one side by a screw but not held down all round, at least unless the electromagnet below, which was of the tubular pattern, was powerful enough to pull it down. In those shown at Philadelphia this actually occurred, the iron membrane being held against the tubular electromagnet by the electromagnetic attraction.

"The telephone shown in Fig. 438 was used as a transmitting instrument, and that in Fig. 439 as a receiver, so that vocal communication was only established in one direction." "The articulation produced from the instrument shown in Fig. 439 was remarkably distinct, but its great defect consisted in the fact [1] that it could not be used as a transmitting instrument, and thus two telephones were required at each station, one for transmitting and one for receiving spoken messages."

"It was determined to vary the construction of the telephone shown in Fig. 438, and I sought by changing the size and tension of the membrane, the diameter and thickness of the steel spring, the size and power of the magnet, and the coils of insulated wire around the poles, to discover empirically the exact effect of each element of the combination, and thus to deduce a more perfect form of apparatus. It was found that a marked increase in the loudness of the sounds resulted from shortening the length of the coils of wire, and by enlarging the iron diaphragm which was glued to the membrane. In the latter case, also, the distinctness of the articulation was improved. Finally, the membrane of goldbeaters' skin was discarded entirely, and a simple iron plate was used instead, and at once intelligible articulation was obtained. The new form of instrument is that shown in Fig. 440, and, as had been long anticipated, it was proved that the only use of the battery was to magnetize the iron core of the magnet, for the effects were equally audible when the battery was omitted, and a rod of magnetized steel substituted for the iron core of the magnet." "At the time the instruments were first exhibited in public the results obtained with permanent magnets were not nearly so striking as when a voltaic battery was employed, wherefore we thought it best to exhibit only the latter form of instrument. The interest excited by the first published accounts of the operation of

[1] [This appears to be a mistake: it has been abundantly shown that this form transmits perfectly.—ED.]

the telephone led many persons to investigate the subject, and I doubt not that numbers of experimenters have independently discovered that permanent magnets might be employed instead of voltaic batteries. Indeed one gentleman, Professor Dolbear, of Tufts College, not only claims to have discovered the magneto-electric telephone, but I understand charges me with having obtained the idea from him through the medium of a mutual friend. A still more powerful form of apparatus was constructed by using a powerful compound horse-shoe magnet in place of the straight rod which had been previously used."

The early forms of Bell's telephone were inconvenient for holding to the ear; and at an early date a form was settled upon capable of serving both for transmitter and receiver. Fig. 440 shows a

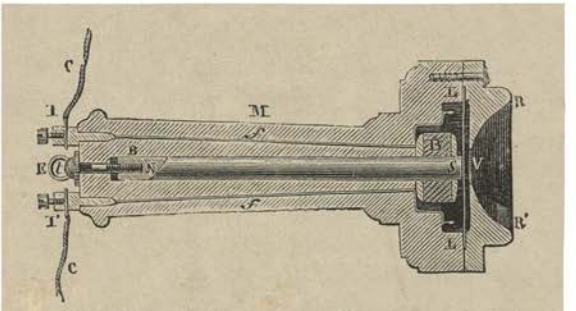

FIG. 440.—Bell's telephone-receiver; ordinary form, sectional view.

transverse section in which the mechanism and functions of each part can be easily seen and understood. At the end of a funnel-shaped mouthpiece having an aperture V is fixed a vibrating plate LL, cut from a sheet of very thin ferrotype about $\frac{1}{10}$ to $\frac{1}{5}$ of a millimetre thick, and covered, to prevent oxidation, with a layer of varnish or tin. This disk is held by its edges between the mouthpiece and the tubular end of the body of the instrument M, which encloses the bar magnet NS and the coil B. The pole of the magnet is placed opposite to the centre of the vibrating plate quite close to, but not touching it. The ends of the wire of the coil communicate by two wires *f f*, placed in the thick part of the handle to the binding screws I, I', to which the circuit wires C and C' are fixed.

The mode of action of this apparatus when acting *as a receiver* at the station distant from the speaker, is easily explained. The electric

current, thrown into the proper fluctuations by the transmitter used by the speaker, flows along the line and ultimately enters the coil on the end of the magnet. It thereby alters the magnetic pull, momentarily strengthening or weakening it as the case may be, and therefore causing the iron armature—the thin sheet of iron—to execute corresponding movements to and fro, which throw the adjacent air into audible vibration.

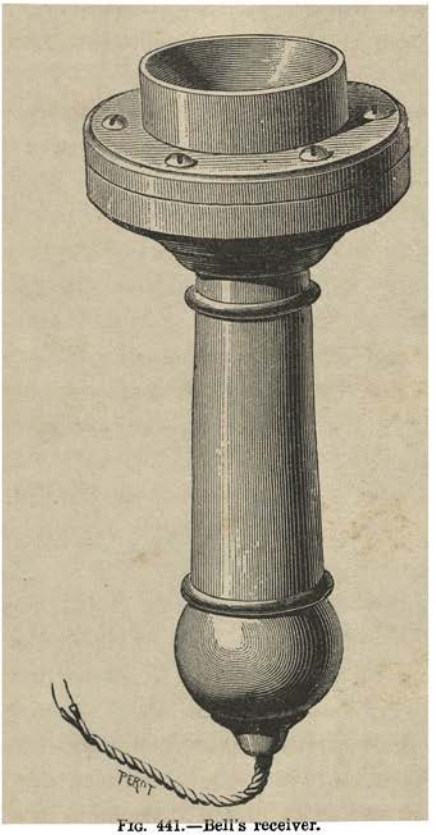

FIG. 441.—Bell's receiver.

To give an account of the transmission of sounds by means of this apparatus, when it is used *as a transmitter*, we must explain what passes when one speaks into the mouthpiece.

The sounds of the voice, concentrated by the blunt conical form of the mouthpiece, impart vibrations to the elastic disk, the movements of which approximately reproduce, with all their variations

in pitch, amplitude and timbre, those of the air disturbed by the voice itself. The movement of the disk, approaching or receding from the pole of the bar magnet, modifies the distribution of the magnetic lines of the field surrounding the pole of the core, and the variations in the number of the magnetic lines of force that thus penetrate the surrounding coil set up corresponding alternating induction-currents in the wire of the coil, which alternating currents flow into the line. and pass to the receiver at the other end of the line.

Count du Moncel and others have debated whether the sounds produced in the Bell instrument when used as a receiver are due to the bodily vibration of the diaphragm, or whether the motion is not chiefly a purely molecular one. It is quite certain now that the diaphragm vibrates as a whole. But it is equally certain that there are audible molecular vibrations even in the iron core of the magnet.

The sounds produced when two magneto instruments are used on Bell's plan, one as transmitter, the other as receiver, are usually very distinct but not loud. In the vast majority of cases, and especially in telephone exchange working, louder articulation is required. Consequently Bell's method of magneto-transmission has been practically abandoned; and telephone engineers have returned to the original method of employing a battery and a separate transmitter working on the loose-contact or microphonic principle. But the convenient form of instrument introduced by Bell is still retained as a receiver.

§ 3.—*Battery Telephones, or Transmitters.*

We have seen how Philipp Reis proposed to use a transmitter to impose upon an electric current generated by an ordinary battery interruptions corresponding to the vibrations of the voice. It will have been noticed that his transmitter, or, as he called that part of his apparatus, the "telephone," consists essentially of three parts: (1) a mouth-piece to receive the sound-waves; (2) a diaphragm or tympanum to collect and concentrate these waves and to vibrate in unison with them; (3) an electric mechanism consisting essentially of two pieces of an inoxidisable conducting material placed in imperfect and loose contact with one another.

We shall now see how in the more modern forms of telephonic transmitter these three characteristic portions of the instrument survive, though the modifications given to them are innumerable. It had long been known that when two conducting bodies are brought together, so that their contact may complete an electric circuit, the perfection of the contact, and consequently the amount of resistance offered to the flow of the current, will be greatly affected by the pressure on the contacts. It is for this reason that most electrical apparatus is furnished with clamping screws, so that loose joints and imperfect contacts may be avoided. But for the telephonic transmitter this imperfect contact that is provided by a loose joint is the vital fact to be utilised and applied. Hence it becomes necessary to inquire what is the best material, form, and arrangement to give to the parts of the working contact pieces so that the joint between them may be the most sensitive and at the same time the most reliable in its action.

As we have seen, Reis habitually used platinum, though he also suggested other materials—namely, brass, copper, iron, and steel. He preferred platinum, however, on account of its greater resistance to oxidation and fusion. Experience has shown that many other bodies will, however, act quite as well as platinum, and there is one which by common consent has been preferred on account of being, whilst perhaps no more sensitive, more reliable in its action. This material is retort carbon, such as is used for battery plates or for the pencils of arc lamps; it has been recognised since the time of Faraday as an excellent conductor, both in its natural form as it occurs in gas retorts as a waste product of the gas manufacture, and in its artificial form as specially prepared in moulds for the purposes above named. It is found, as we shall specially narrate in the section devoted to microphones, that the contact-joint between two pieces of this material is excellent for the purpose of telephonic transmission. The suitability of this material was discovered almost simultaneously in 1878 by Hughes in England, and Luettge in Germany. But before the serviceableness of this material was discovered there were other suggestions of a kindred nature. As remarked above, it had long been known that pressure affected the resistance offered by a joint to the passage of electric currents. The attention of the late Count Du Moncel had been drawn to this

fact; and he made a number of researches on the influence of pressure on the resistance when various materials were employed. In particular he noticed that the variations of resistance were well marked when charcoal formed one of the substances at the contact. Almost the same facts had been investigated also by M. Clérac, a well-known French telegraph-engineer, who had even proposed to employ tubes packed with charcoal powder, and having adjusting screws in their ends, as a means of introducing a variable resistance into an electric circuit. Quite independently of these observers the same phenomenon of apparent change of electric resistance under the application of pressure was noted in America by Mr. Edison, who was using plumbago. Many persons, and amongst them at one time Mr. Edison, upheld the view that the electric resistance of such material itself is diminished by the application of pressure. Others (including the editor of this book) have maintained that the resistance of the material itself is not appreciably altered by pressure, but that the great changes of resistance that are observed occur in the joint between the two surfaces.

No sooner was the fame of Bell's telephone raised abroad than other inventors set to work, and Edison, basing his efforts on the early instruments of Philipp Reis, sought to produce a battery telephone, or transmitter, which should be more powerful than the magneto-induction transmitters employed by Bell. Edison's first transmitter was indeed nothing more than a Reis's apparatus arranged with several membranes to be simultaneously thrown into vibration, and using for the contact parts not platinum against platinum, but platinum against plumbago. After many experiments he adopted a form of instrument shown in Fig. 442, which, though in exterior form it resembles a Bell's receiver, is in its interior wholly different. There is first a coned mouth-piece, M, into which the speaker speaks. Behind this is a diaphragm or tympanum, L L, which takes up and collects the vibrations and imparts them to the electric mechanism behind it, which is of the following nature. A and B are two thin pieces of platinum, connected respectively to the terminals P and P' which are joined to the circuit. Between A and B lies a button, C, prepared from the finest quality of lamp-black consolidated in a special die under immense pressure. The current in flowing from A to C and from

C to B experiences a certain amount of resistance. This resistance is found to vary with pressure, being diminished when the pressure applied is increased; increased when the pressure is diminished. Increase of pressure makes a more perfect contact, say one school

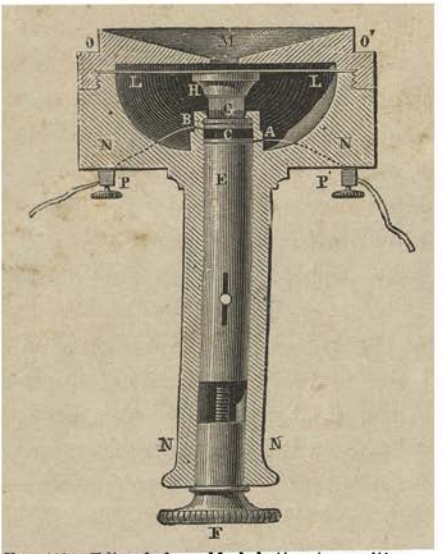

FIG. 442.—Edison's lamp-black button transmitter.

of electricians (including the editor of this work): increase of pressure diminishes the resistance of the button itself, say others. However it be, the button serves as a transmitter, and varies the

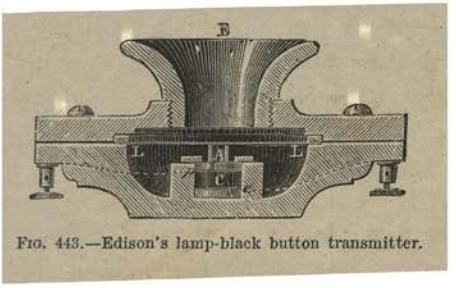

FIG. 443.—Edison's lamp-black button transmitter.

strength of the electric current in a manner corresponding approximately with the vibrations of the voice. A presser of cork, H communicates the vibrations of the diaphragm to the electric mechanism, or "electric tension-regulator," as Edison calls the

device. An adjusting screw, F, serves to fix the initial pressure to which the various parts of the device are subjected.

In the model which Fig. 443 represents, the handle of the apparatus is suppressed, the regulation is made by means of a screw situated under *e*. The platinum plate *p* rests on the carbon conductor C, with a disc, *b*, in aluminium, surmounted by a small cylinder of iron, A, in contact with the vibrating plate L L.

The last modification of Edison's transmitter is shown in Fig. 444. The disk is placed on a support, which a screw moves near or far from the vibrating plate, and contact is made in the centre of the plate, by means of a plate of platinum which is surmounted by an ivory button in the form of a hemisphere.

Fig. 445 shows how the apparatus of Edison's system is arranged

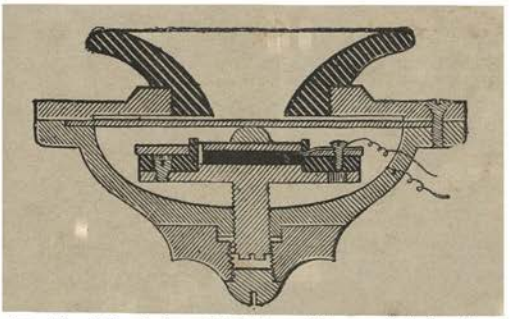

FIG. 444.—Edison's lamp-black transmitter; perfected pattern.

in a telephonic station. The receiver, shown in the drawing, is that which will be hereafter described under the name of the "pony-crown." It is important to remark that the currents of the battery, after having undergone the variations which the vibrations of the plate communicates to them by means of the conductor with variable resistance, are not sent directly to the receiver; they traverse the primary wire of a little induction coil, and it is the secondary wire that is put in connection with the receiving apparatus. On the left is the transmitter, which by means of a jointed support is maintained with convenient inclination at the height of the mouth of the person sending the message; underneath a desk on the right the pony-crown receiver is suspended in the position of repose; as soon as the bell indicates a call it is unhooked and lifted to the ear. This arrangement is applied to the telephones of subscribers; in

telephonic offices the transmitter and receiver are sometimes joined by a bent spring, which serves as a handle, and they can thus be held simultaneously one to the ear, the other to the mouth.

Many other transmitters remain to be described, but as in most of these the fundamental part is a true "microphone," we will defer noticing them until we have given a description of this famous apparatus, the inventor of which is Professor Hughes.

Another class of battery transmitter is that in which a liquid is interposed at the working-point of the circuit. Elisha Gray devised

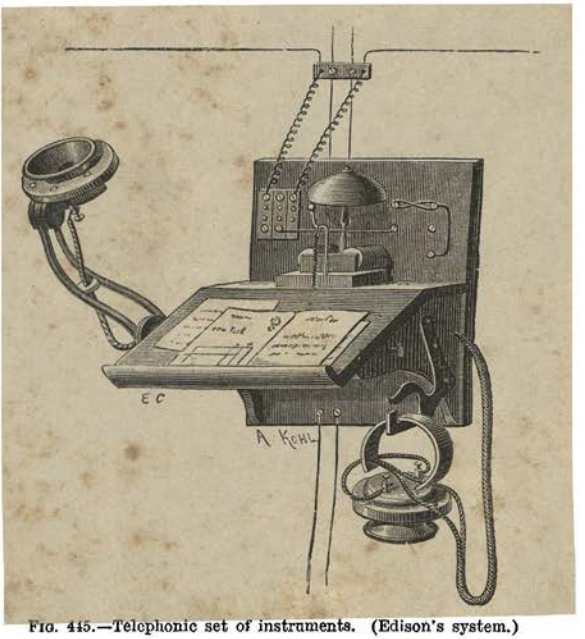

FIG. 415.—Telephonic set of instruments. (Edison's system.)

such a transmitter, in which a platinum wire attached to a diaphragm dipped down to a certain depth, nearly to the bottom, into a cup containing some conducting fluid, such as acidulated water. Other liquid transmitters have been devised by Graham Bell and by Edison.

§ 4.—*Telephonic Receivers of Various Forms.*

Since Graham Bell's researches, the arrangements of the receiver have been modified in many ways with the aim of improving it; most

of these modifications being only of secondary importance, we shall describe but two or three of the most interesting.

Siemens's receiver is distinguished from Bell's by the magnet having the form of a horse-shoe, furnished with two pole-pieces which each bear a coil opposite the vibrating diaphragm; and those that are to be used as transmitters are sometimes supplied with a signal in the form of a whistle placed at the orifice of the mouth-piece. A stem fixed to the tube of the whistle rests on the plate, and when you blow into the instrument it communicates the vibrations of the tube to the diaphragm. The result is that the receiver gives out a whistling sound loud enough to be heard at a considerable distance. The call being understood, the whistle itself is then detached, and the speaking is done as usual.

Siemens's telephone has the inconvenience of being rather heavy, but this defect is compensated by its power; the person speaking may be two yards distant from the transmitting instrument, and the listener can understand even though at a distance of some feet from the receiver. Siemens's form of instrument is adopted in the Imperial German Post Office and in the German Army and Navy.

Gower's form of instrument is also remarkable for the power of the sounds emitted; they can be heard, by the aid of well-constructed apparatus, over very large halls. Unfortunately the sounds have a very decided metallic ring, and the words are not sufficiently clear.

Fig. 446 shows the arrangement of the Gower receiver. C shows the magnet in the form of a semicircular ring, the arms of which placed on a diameter, have their oblong pole-pieces turned up opposite to each other at a little distance from the middle. Coils of very fine wire surround them, and are connected with the binding screws of the circuit outside the telephone. The iron diaphragm, thicker and bigger than the ferrotype plate used in Bell's form, is fixed to a flat brass box, B, which forms the lid of the box C. In the centre of the lid is fixed a short speaking-tube, used either for speaking, by applying the mouth to the opening, or for hearing, by putting it to the ear. In the drawing there is shown at a a bent tube containing a little tongue which vibrates when you blow into the speaking-tube; this the vibrations of tongue, transmitted directly to the diaphragm, set up induced currents, which produce in the receiver a sound as loud as that of a cornet, serving as a signal call. When speaking in

a low voice, a speaking-tube is used at both stations, but if the words are to be heard at a distance—for example, at different parts of a large hall—instead of a tube at the receiver, a large resonator or speaking-trumpet is used. The power of Gower's instrument is due to the good magnetic arrangements: the use of a very powerful magnet, the great size of the vibrating diaphragm, and the sonorous metal box, which increases the sounds emitted.

The Ader receiver, of which Fig. 447 represents the different parts, seen inside and out, is principally distinguished from the Bell telephone by the addition of a piece of soft iron in the form of a ring x x, which is used as a super-exciting armature. The magnet, of a cir-

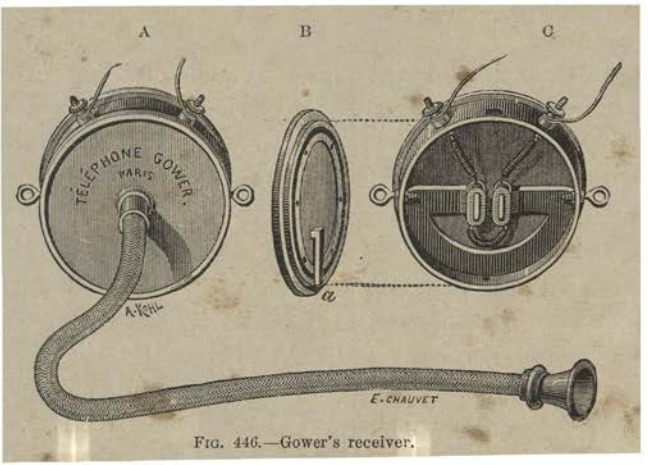

FIG. 446.—Gower's receiver.

cular form, has its poles surrounded with coils. B B, like the Gower telephone, having their ends opposite the ring, and in front of the plate constituting the diaphragm. The influence of the super-exciting armature is to increase, by its mass, the intensity of the magnetic reactions between the diaphragm and the poles of the magnet, and consequently of the induced currents developed in the wires of the coils by the vibratory movements of the plate.

The Ader instrument is chiefly used as a receiver, and in this case a microphonic transmitter is employed, as we shall see when speaking of battery telephones. But the same apparatus can be also used as transmitter and as receiver: it then acts without a battery, like those forms of Bell's telephones that are provided with permanent magnets.

We shall conclude this paragraph by describing some telephones

with double diaphragms. The aim of the inventors of these is to increase the intensity of the currents developed under the influence of the voice; for that purpose they make the vibrations of the air react, in the opening or mouth-piece of the transmitter, on two or more insulated diaphragms, each armed with an electro-magnetic attachment.

Sometimes, as in a form suggested by Elisha Gray, there are two pieces of apparatus like Bell's receivers connected, having a common mouth-piece E (Fig. 448), and, to the right and left, two tubes each leading to a diaphragm which vibrates opposite the pole A of the horse-

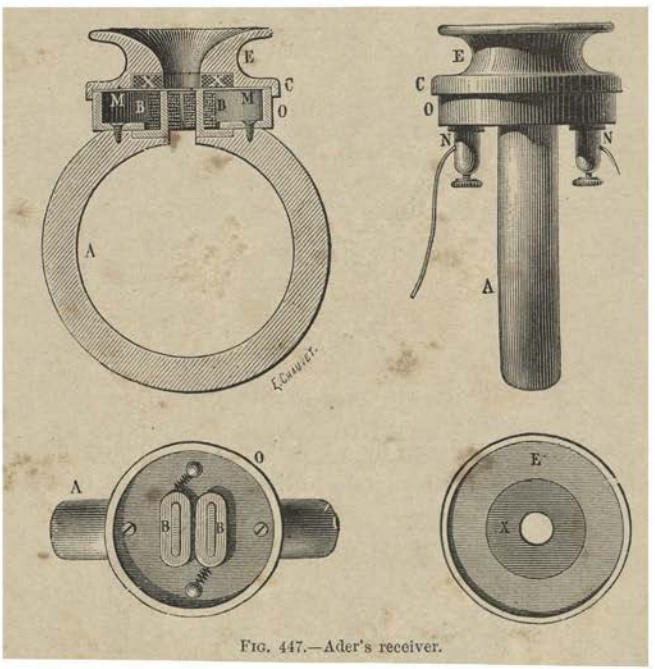

FIG. 447.—Ader's receiver.

shoe magnet U. Sometimes, as in Trouvé's system (Fig. 449), a tubular magnet is placed perpendicular to the two diaphragms, one of which is pierced in its centre with a hole, *a*, the same diameter as the hollow part of the magnet. The coil surrounds the magnet entirely, and a series of vibrating plates, *n n n*, is placed in a parallel direction between the first ones. The following is what Trouvé says of the advantages of this arrangement: "The ear," he says, "placed at *a* perceives directly the sounds produced by the first plate M, and those of the second which come to it through the interior of the magnetic tube.

This new arrangement is most useful for comparing experimentally the results furnished by a telephone with one diaphragm (Bell's

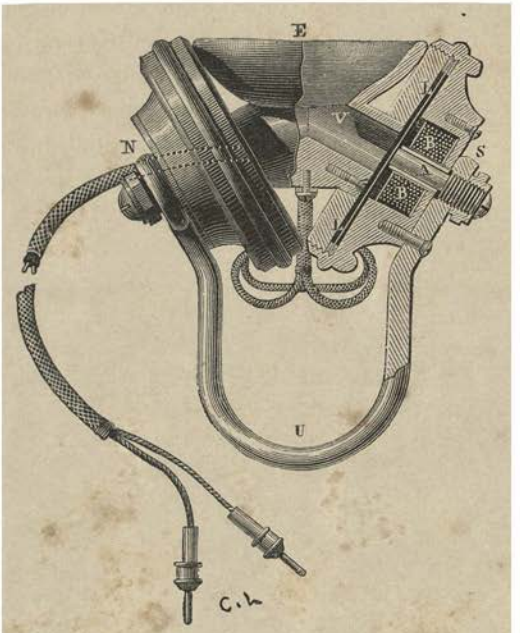

FIG. 448.—Gray's double receiver.

receiver) and those produced by a telephone with many diaphragms. It is sufficient to listen alternately to the two sides of this telephone

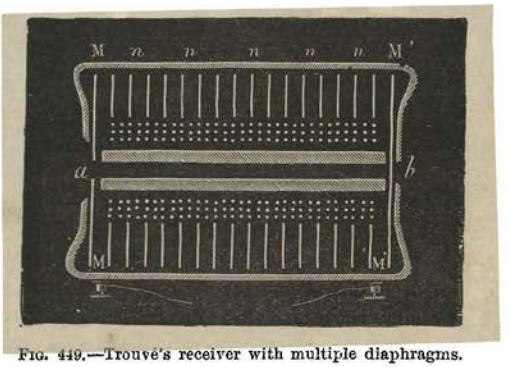

FIG. 449.—Trouvé's receiver with multiple diaphragms.

to perceive immediately the difference of intensity of the sounds produced. Those collected at a on the side of the pierced membrane,

seem to have decidedly double the intensity of those collected at *b* on the side of the unpierced membrane, which constitutes an ordinary telephone. The difference is still more striking, if, in transmitting or receiving a sound invariable in intensity through a multiple telephone, you prevent the diaphragm M, from vibrating."

Instead of multiplying the vibrating diaphragms, the number of magnets on which these plates act has been increased.

We may cite among apparatus of this kind the crown telephone of Phelps, so called from the exterior form, due to six magnets turned in

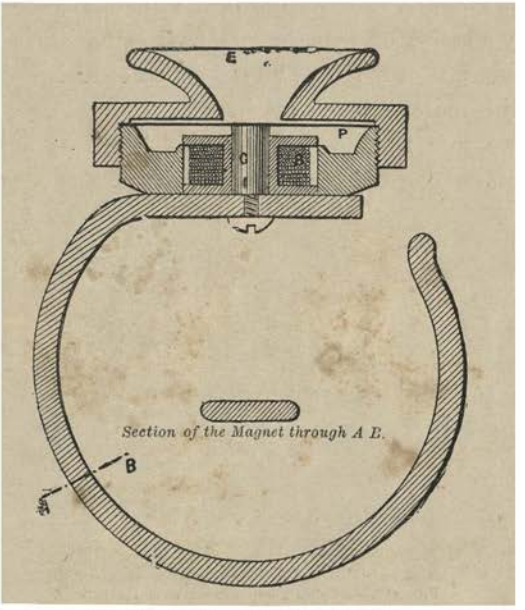

FIG. 450.—Phelps's pony-crown receiver.

the form of a ring. The six poles of the same name converge towards the centre of the diaphragm of the telephone, whilst the six other poles rest on the outside edge of the same disk. The consequence is the magnetic field is extended, and strengthened, and the power of the instrument increased. The advantage, however, of this arrangement is not considerable, for the same inventor has substituted for it the pony-crown (Fig. 450), which only differs from Bell's telephone by the flat form of the magnet ring, and by the soft iron cylinder G, which serves as a spindle for the coil, and is placed perpendicularly in the centre of the diaphragm.

§ 5.—MICROPHONES.

As the microscope renders perceptible to the sight objects that escape it because of their smallness, so the microphone[1] helps the ear to seize sounds the feebleness of which prevents their being heard in ordinary circumstances. In a general way, it is an amplifier of sonorous vibrations, or of the mechanical effects which produce them.

Professor Hughes, the inventor of the microphone, was led to his discovery by a series of experiments having for their object to discover the influence of sonorous vibrations on electric conduction. We give one of his most curious experiments.

Place two iron nails on a horizontal board at a little distance from each other (Fig. 451), and fasten to these two wires in circuit

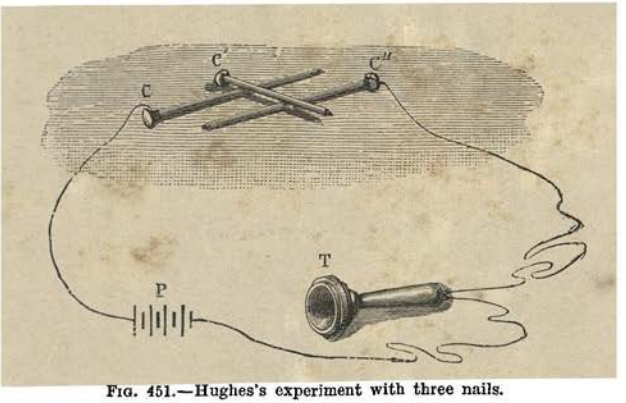

FIG. 451.—Hughes's experiment with three nails.

with a battery and a telephonic receiver. If you close the circuit by means of a third nail placed transversely on the two others, you have an arrangement sensitive enough to enable you to perceive slight noises, such as those of ordinary respiration. The transmission of sonorous vibrations is made by the imperfect contact of the two nails with

[1] We must be careful to remember that the analogy of microscope and microphone suggested by their names is only that of the effects produced. There is no proof that it is the sounds themselves that are amplified. Though the theory of the microphone is not more developed than that of the telephone, it seems probable that it is more a transformation of molecular movements into sonorous vibrations, than a true amplification.

the third which rests slightly on them. The movements which constitute the sounds are transferred to the conductors, modify the pressure and the conduction at the points of contact; hence these variations which follow those of the noises, or of any sounds whatever emitted at a short distance away, alter the battery currents in the wire, and act on the receiver of the telephone. Hughes noticed the advantage of employing, instead of metal contacts, the material carbon, which allows of a slight and constant pressure being put on the contacts, and is besides unoxidizable.

By metallizing the carbon pieces with mercury, Hughes found the

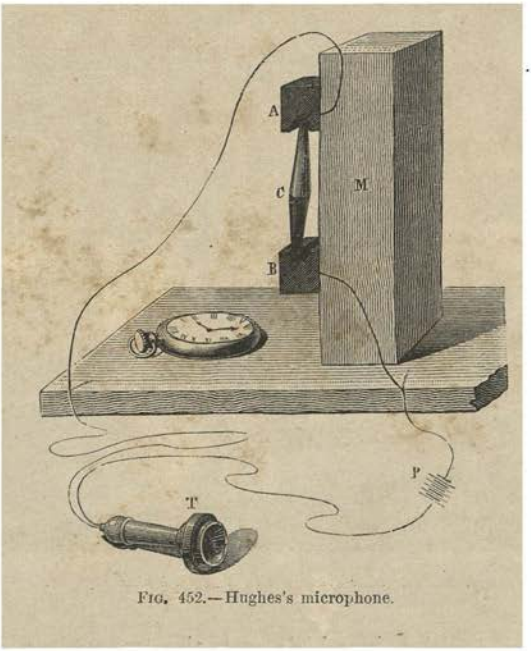

FIG. 452.—Hughes's microphone.

effects to be improved. To procure this material he used the charcoal employed by artists for their drawings, heated it gradually to a white heat, then plunged it suddenly into mercury, so that the metal was instantaneously introduced in the form of globules into the pores of the charcoal thus metallizing it, and making it conduct better. He also tried carbon covered with a deposit of platinum, or impregnated with chloride of platinum: none of these materials were found superior to the preceding. Pine-wood charcoal heated to whiteness in an iron tube containing tin and zinc, or any other volatile metal, will become

metallized; the conditions will be good if the metal is in a fine state of division in the pores of this body. Iron introduced in this way into charcoal is one of the metals that gave him the best effects. Pine-wood charcoal, though a bad conductor, acquires in this way a high conducting power.

Hughes arranges his *microphone* as follows, when it is required to be of great sensitiveness. A and B (Fig. 452) are two cubes of carbon arranged one above the other against a block of wood, M. In them

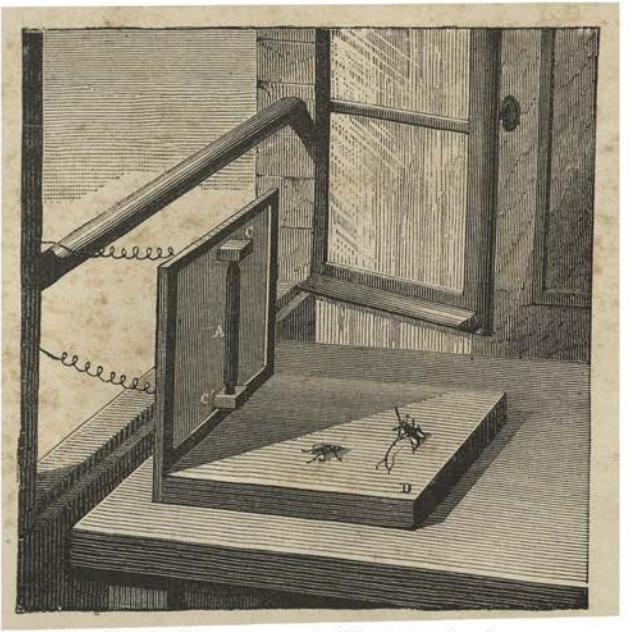

FIG. 453.—Another arrangement of Hughes's microphone.

are bored two cavities, in which rest the two points of a carbon pencil, cut spindle-shaped, and which is thus ready to be shaken by the least movement; for its vertical position is one of an equilibrium easily disturbed. The two carbon blocks are joined in circuit with a battery, P, and a telephone receiver, T. It is usual to place the microphone upon a piece of pine-wood board.

When the microphone is used, the board should be placed on a cushion, or on bands or tubes of india-rubber, so as to intercept all external vibrations. This being done, the apparatus is extremely sensitive to the most feeble sounds that are imparted to it. Such

slight imperceptible noises as the tick of a watch, and those produced by the movements of the feet of an insect crawling on the board, produce the most extraordinary sounds in the receiver.

The arrangement of the microphone has been varied in innumerable ways, and we shall pass in review some of the microphonic transmitters constructed on this principle. But first we may mention a fact clearly proving that it is not only the sonorous vibrations that are amplified, but the mechanical movements which are communicated to the carbons, and which cause the electric conductivity at the contacts to vary.

If the microphone, instead of being fixed to the board on which the watch or the insects are placed, is suspended in the air, then the

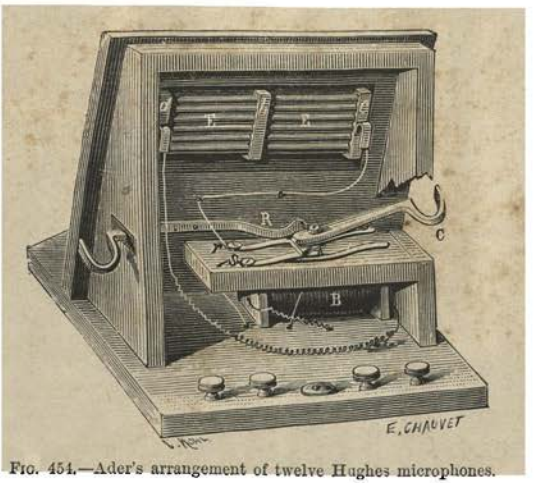

FIG. 454.—Ader's arrangement of twelve Hughes microphones.

sounds proceeding from these objects are scarcely heard in the receiver; but, on the other hand, the sonorous vibrations transmitted by the air, such as those of the voice, are then much more clearly distinguished.

In order to increase the effective working of microphonic transmitters, the contacts have been multiplied. In Ader's microphonic transmitters the number of carbon pencils is a dozen, arranged in a double row between three pieces of carbon pierced with twenty-four holes, as shown in Fig. 454, where the apparatus is seen from underneath. This row of pencils is fixed to the lower side of a little pine-wood board, D (Fig. 455), sloped liked a desk-lid. B is the

induction coil of the transmitter P, C is a suspending hook, which serves also as a switch for the bell circuit, there being a call-button at

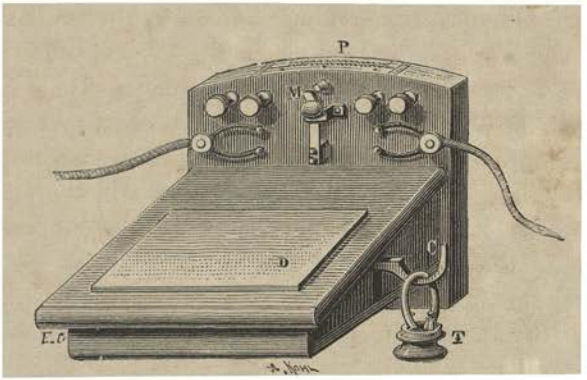

FIG. 455.—Exterior view of Ader's transmitter.

M. The apparatus rests on a leaden stand, which is itself supported on india-rubber feet to prevent vibrations or jars that would introduce

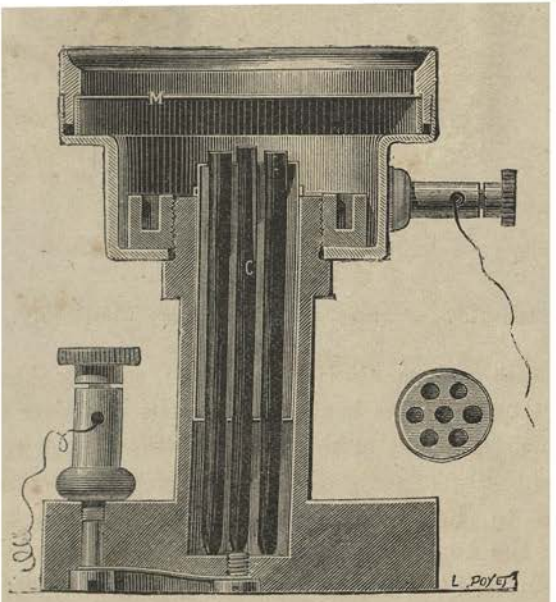

FIG. 456.—Transmitter of Paul Bert and d'Arsonval.

disturbing noises that would interfere with the sounds to be transmitted. It was the transmitters of this system employed in the

theatres which excited so much curiosity among the visitors to the Electrical Exhibition at Paris in the autumn of 1881.

In the microphones arranged by the late M. Paul Bert and M. d'Arsonval, the carbon pencils are grouped in parallel. The following is a description (taken from Du Moncel) of three systems designed by these inventors, as represented in Figs. 456, 457, and 458. Fig. 456 is composed of a series of carbon pencils placed vertically between

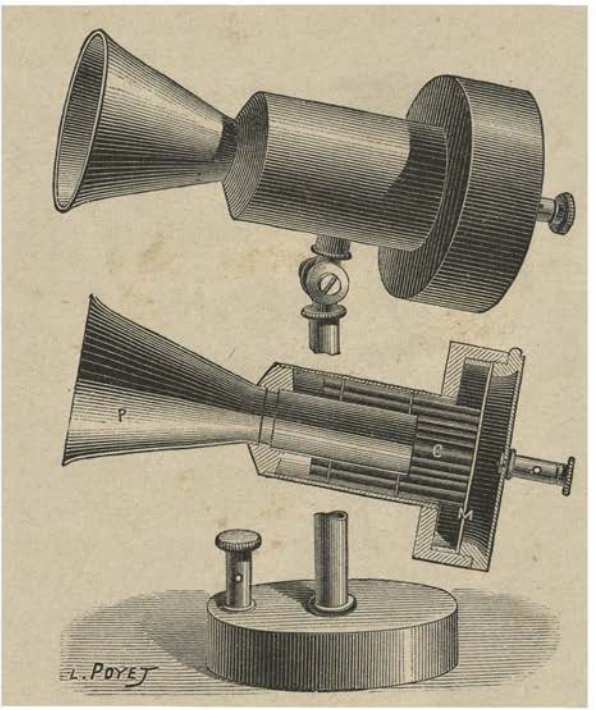

FIG. 457.—Transmitter of Paul Bert and d'Arsonval. (Second form.)

two plates pierced with holes, which act as guides to them. Their lower parts dip into a bath of mercury at the bottom of the tube, which presses them gently upwards as they float in the liquid. The tips of these carbons rest lightly against a diaphragm of nickel or platinum, which receives the vibrations of the voice. The current enters by the diaphragm, descends, dividing itself amongst the carbons, and leaves by the mercury bath.

The pressure of the carbons against the diaphragm is easily

regulated by varying the level of the mercury in the tube, and it is of the same amount for each pencil, thereby realizing one of the good conditions in the construction of such apparatus. This instrument has furnished very good results, but as the employment of mercury is scarcely practicable, Bert and d'Arsonval were obliged to seek a more simple combination, and they designed those represented in Figs. 457 and 458, both of which are based on the action of gravity. The two patterns are applicable for different cases under varying conditions,

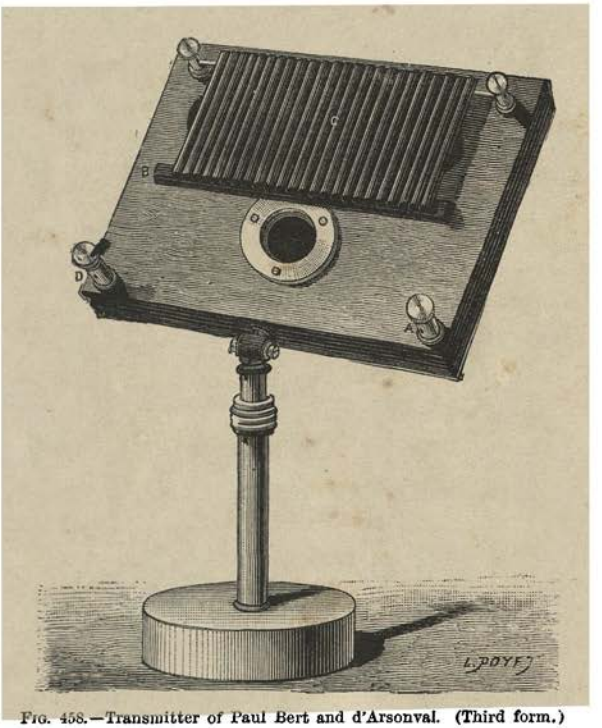

FIG. 458.—Transmitter of Paul Bert and d'Arsonval. (Third form.)

One of these (Fig. 458) readily transmits speech to a great distance even when the person who speaks to the transmitter speaks so low as not to be heard by his neighbour. The other, on the contrary, instead of avoiding outside noises, takes up the words or the song, though placed at a very great distance from the point whence the sounds proceed.

The first of these two arrangements (Fig. 457) is composed of a vibrating diaphragm of platinum or nickel, on which rests, per-

pendicularly to its surface, a series of carbon pencils inserted into nickel tubes, which tubes slide freely into two rings; the carbons are only a few millimetres longer than the tubes, and they are good conductors. Through the two rings supporting the tubes passes a central tube, terminated outside by a mouth-piece, the other extremity, C, of which opens at the centre of the membrane.

The vibrations of the voice collected by the mouth-piece are transmitted to the diaphragm by means of this tube. The diaphragm is fixed in a vulcanite box, and receives the current through the clamping ring. This current is then transmitted to the pencils, and thence to the rings, which conduct it to the foot of the apparatus. This foot, which is entirely of metal, is hinged to allow of the instrument being inclined more or less; and by this means the pressure of the pencils on the diaphragm can very easily be varied.

This transmitter can be traversed, without inconvenience, by currents having an intensity of from 15 to 20 ampères, and the voice produces variations of from 1·3 to 1·2 ampères, or sufficient to work several Morse telegraphs. In these conductors the voice is transmitted with great intensity.

Naturally with this system an induction coil and an ordinary telephonic receiver are used.

Their third arrangement (Fig. 458) is based exactly on the same principle. It is composed of a sounding box like that of stringed instruments, or of a simple light board of ebonite or pine which supports the row of contacts. These contacts consist of a series of small cylinders of nickeled carbon, all threaded on a metal wire stretched horizontally across one side of the box. Their movement is independent, and each of them rests on a transverse slip of carbon which serves as a collector, and which receives the vibrations of the sounding box or board. The pressure of the carbons on the collector is more or less strong according to the inclination given to the case, which can be mounted on a hinged foot, or suspended in a room by the two wires which bear the current. The current comes in through the wire at the top, divides itself between the pencils, and passes off through the bottom slip of carbon. The number of contacts may be as many as is found desirable.

According to d'Arsonval, this apparatus takes up the least sound with marvellous facility, and constitutes, as it were, a large "ear" of

great delicacy. A conversation in a very moderate voice is taken up at more than 10 yards away from the instrument without the voice being at all raised.

The microphonic transmitter of Dr. Boudet of Paris (Fig. 459) consists of six balls of retort carbon inside a glass tube of rather larger diameter. The balls can therefore slide along the tube without sensible lateral movement: so that there are six contacts united in series. A copper cylinder M rests on one side, and is attached to the centre of an ebonite diaphragm adapted to a telephonic mouth-piece E.

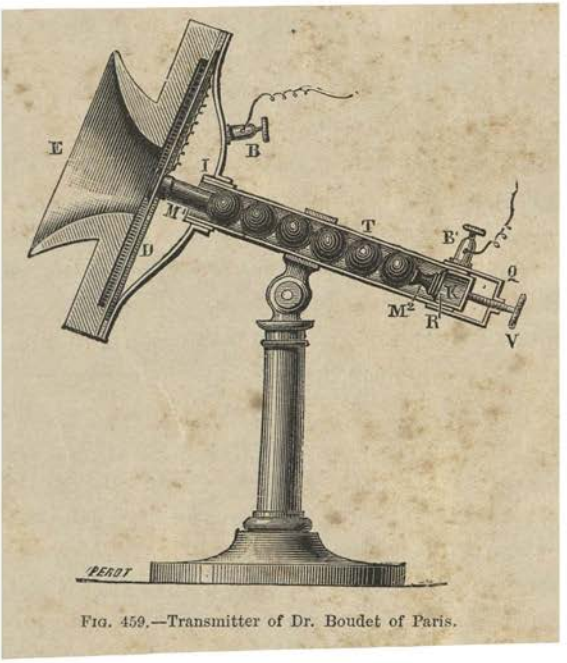

FIG. 459.—Transmitter of Dr. Boudet of Paris.

A screw V, which presses against a piece of hollow copper K, allows the operator to regulate the pressure of a little grooved piece of copper M_2 against the sphere next to it in the tube, and thus serves as a regulator to the apparatus. The wires of the battery and of the telephonic circuit are attached to the terminals B and B′, which communicate metallically with the masses M and M_2. The tube is mounted on a jointed foot, admitting, like a telescope stand, of all possible inclinations. The variations of resistance produced by the vibrations are instantaneously communicated to all the spheres, as

in the well-known experiment with elastic balls. The inventor has obtained very good results by metallizing the balls with mercury, as Hughes did with the charcoal used in his early pencil microphones.

We might describe many other microphonic transmitters, such as those of Maiche, Gower-Bell, Herz, Locht-Labye, and others. But their principle is always the same; they differ from those we have described only in different arrangements of multiple contact, united either in parallel or series. In Locht-Labye's there is only a simple carbon cone fastened on to a plate of cork suspended by slight springs to a frame: this cone is pressed by a metal spring.

All these systems of telephonic transmitters work with ordinary magneto-receivers. But it may be mentioned that though this is the kind of receiver used in practice, yet it has been found possible to use mere microphones themselves to receive sounds. This extraordinary fact confirms the supposition that the molecular movements at the contact points constitute the essential mode of action in microphones. And we may further mention that words have been transmitted by means of magneto-telephones without any vibrating plates or diaphragms, but merely by the vibrations of the central cores.

§ 6.—*Applications of the Telephone to Exchange Working.*

A few words remain to be said on the different applications of telephonic apparatus.

It might have been thought that the telephone would have superseded the electric telegraph. This method of correspondence has in fact a great advantage over the former, in that there is no need of previous education to use it, whilst the simplest telegraphic apparatus cannot be worked except by the means of skilled hands, for which a methodic apprenticeship, and sometimes a long and difficult one, is necessary, But notwithstanding this advantage, which is not to be disdained, telephonic communication has grave inconveniences: the first is, that which is common to dial telegraphs also, it leaves no record of the messages transmitted. Another fault is the relative slowness of the communication: we have seen in the preceding chapters what efforts have been successfully made to devise automatic, duplex, quadruplex, and even multiplex telegraphic systems, by

means of which commercial intercourse can be carried on with the rapidity of transmission which is necessary on busy lines. In this respect the telephone cannot rival the apparatus in question. Moreover, telephonic communication is subject to perturbations, at which we have already hinted, and which are caused by leakage of the currents in the line, by the inductive influence of neighbouring wires, and by confusion of signals produced by the leakages from neighbouring currents.

Telephonic communication will probably therefore never be in itself a dangerous rival to electric telegraphy. Nevertheless it has already acquired great practical importance, under special conditions. In great administrative concerns, in the army and the navy, in large

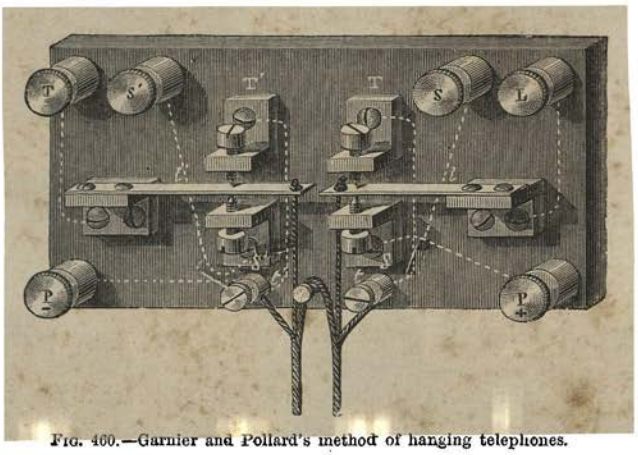

FIG. 460.—Garnier and Pollard's method of hanging telephones.

factories, in mines, ports, and other centres of commerce, and the like, the telephone is capable of rendering signal services. Everywhere that there are frequent orders to transmit, this system is far preferable to telegraphy, for the reason given above, that anybody can transmit or receive the orders in question. In important centres of commerce or industry and in busy city life the telephone has now become a necessary means of communication.

Companies are formed to act as intermediaries between private people: in all the more important towns of the United States, in England, and in large towns on the Continent, telephone exchanges find their clients steadily increasing, and this movement must grow in the near future.

We cannot enter into all the details necessary to explain how an entire telephone exchange system is worked, and shall therefore only attempt a brief account.

The work of a telephone exchange is to put into communication all its subscribers in the same town. Usually each subscriber has a

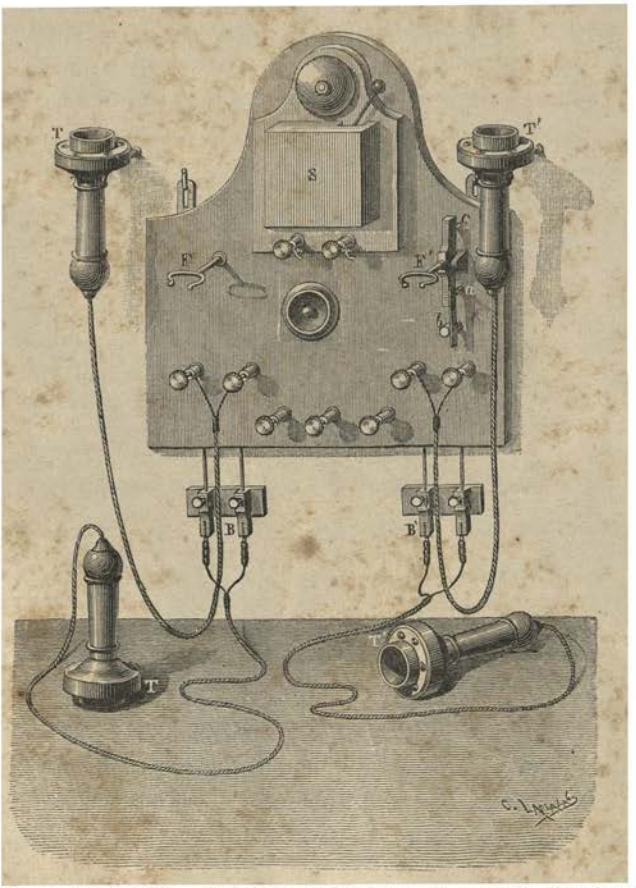

FIG. 461.—Breguet and Roosevelt's method of hanging telephones : F', suspending fork arranged as a key-switch, which puts the bell into circuit, to be operated by the weight of the receiver.

special line, which runs into a central office, and when any subscriber wishes to communicate with any other subscriber, he sends a signal which rings the bell of the central office. An electromagnet in the local circuit corresponding to the subscriber's number on the list is brought into action by the current, it attracts its armature and causes

a little hinged flap or plate of metal to fall, revealing to the operator in the exchange the number of the subscriber who has called. This apparatus is called an indicator or annunciator. Underneath the little hinged shutters of the annunciators are a series of switches all arranged in proper order, one connected with each subscriber's line. The whole arrangement of annunciators and switches is called a *switch-board*, and its form is seen in Figs. 462 and 463. The object of these switches is to enable electric connexion to be made rapidly between the lines of the different subscribers. When the operator observes that the shutter of any subscriber's annunciator has dropped he

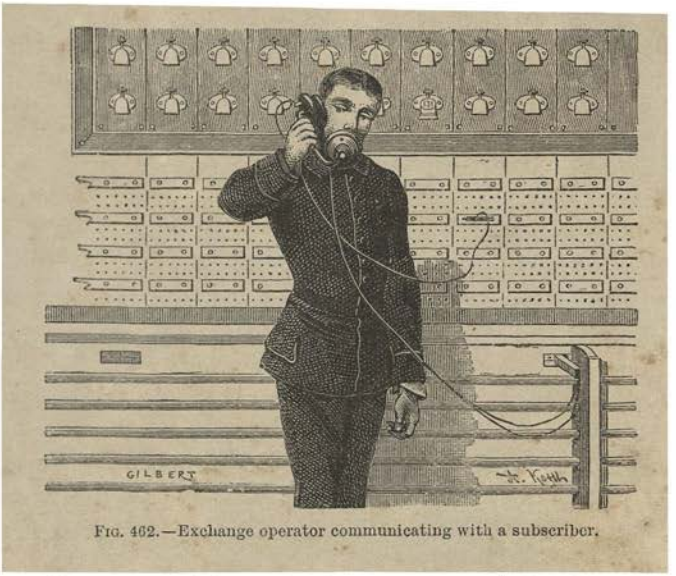

FIG. 462.—Exchange operator communicating with a subscriber.

connects his own receiving telephone to the switch belonging to that subscriber's line, and listens. The subscriber may ask to be put in communication with another subscriber on the same exchange, or with another exchange in some other part of the same town. In the first case the operator in the exchange rings up the subscriber who is wanted, and then puts the two subscribers into communication with one another by connecting their switches together. This may be done by a flexible woven-wire cord, furnished with a tapering piece of metal (called a jack-knife) at each end. If one end of this cord is connected through one switch to the first subscriber's line, and the other through the other switch to the second subscriber's line, there

FIG. 463.—Switch-board of the Central Exchange in Paris.

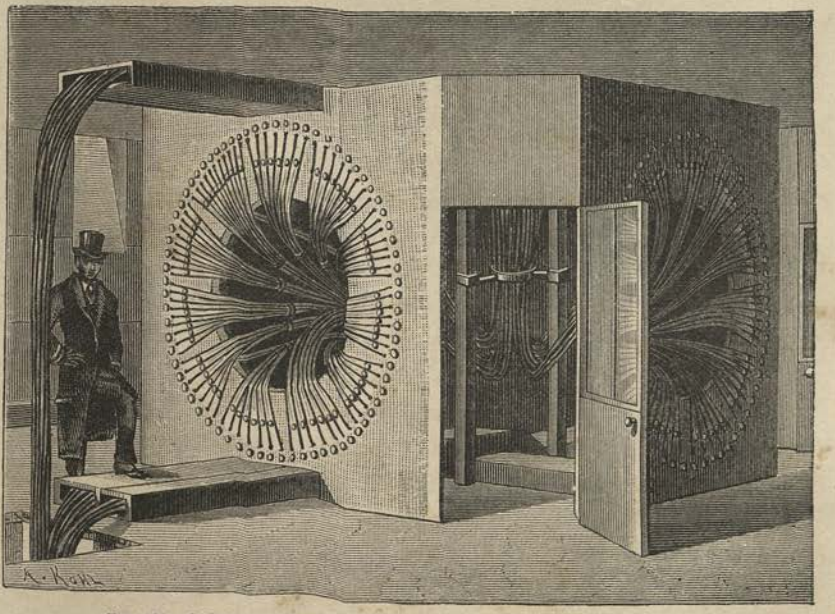

FIG. 464.—Central Exchange in Paris. Arrangement of the in-coming wires.

will be a clear electric circuit through from one to the other, and they can communicate as long as their lines are connected at the switch-board.

The installation of telephone exchange systems in large towns (at Paris there are ten local exchanges, with one central exchange) has compelled inventors to solve several problems of electric mechanism. Many of these solutions deserve from their ingenuity to be described; but space fails us, and we are obliged to send the reader to special works on the subject of the Telephone.[1]

§ 7.—*Telephones in Theatres.*

Telephony, when even in its infancy, was an object of great enthusiasm, even infatuation, as very naturally happens whenever an important and unexpected invention is announced. A thousand fancied applications were suggested, each more marvellous than the last. We have mentioned some of those which have passed into actual use, at least in great towns. It remains for us to say a word on the attempts which have been made in another direction to meet one of the wants of the present time. It was hoped that by means of this marvellous instrument persons might enjoy at their own homes concerts and theatrical representations, might attend meetings and lectures, and might hear sermons, without stirring from the fire-side. Experiments that have taken place from time to time have proved that these applications of the telephone are not absolutely unrealizable, but they are far from being all realized at present in a practical way.

We cannot however pass over in silence the most remarkable, and the most decisive of these experiments; we mean the telephonic arrangements organized in the autumn of 1881 at the Palais de l'Industrie in Paris in four rooms at the Electrical Exhibition. A numerous and impatient public was able every evening to listen to the representations going on at the Opera, to hear the voices of the singers, the orchestral accompaniments, and even the murmurs and applause of the spectators.

[1 The best works hitherto published on the technicalities of telephonic working are those by Grawinkel and by Wietlisbach.—ED.]

The transmitters used for this purpose were Ader's pattern which we have previously described, having a double set of Hughes's microphones arranged in a suitable box. The distance separating the Opera from the rooms where the performance was heard being only $1\frac{1}{4}$ miles, each transmitter was able with a suitable battery to supply currents to eight receivers of Ader's pattern (Fig. 447, p. 706). Twelve transmitters, each having its own separate battery and induction coil, were placed on each side of the prompter's desk, along the balustrade, in front of the stage, as shown in Fig. 465.

Underground wires from the Opera House to the Exhibition connected the transmitters with the receivers at the other end, and various precautions were taken to render the hearing as perfect as

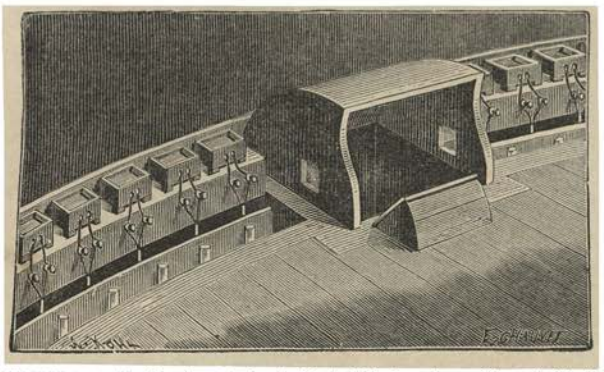

FIG. 465.—Stage arrangements, showing a series of Ader's telephone transmitters beside the footlights.

possible under these exceptional circumstances. The microphonic transmitters used were fixed on leaden blocks, resting on indiarubber bases. The reason of this arrangement was to prevent the microphones from being affected by the vibrations and the noises which would result from the shaking of the floor of the stage by the movements of the actors, and of the ballet-dancers. The inertia of the masses of lead effectually stopped these stray vibrations and noises. An interesting innovation made by Ader in the method of hearing is that which consists of putting each hearer into separate communication with the two sides of the stage. Whilst one of the receivers—that, for example, which the listener is to place to the right ear—is connected with a transmitter situated at one side of the stage, the other receiver, to be placed at the left ear, is connected with the

transmitter placed on the other side of the stage. It is easy to see the reason of this arrangement. All the transmitters are simultaneously affected by the same sounds—for example, by the vibrations

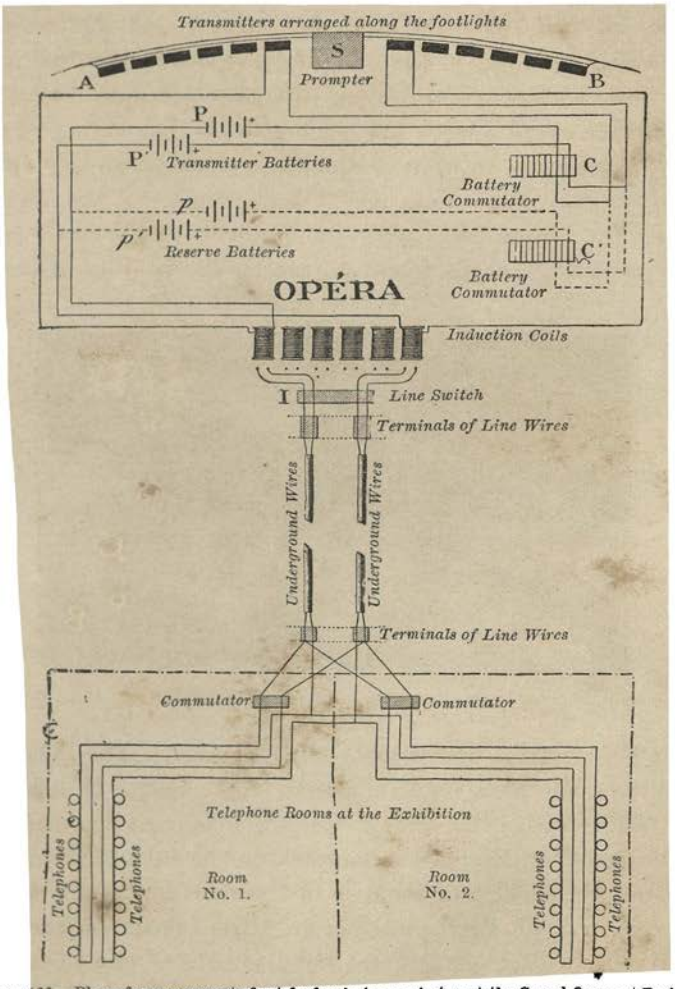

FIG. 466.—Plan of arrangements for telephonic transmission at the Grand Opera at Paris.

of the voice of a singer. But this singer, according to the place which he occupies on the stage, is not at the same distance from each of them; consequently the song will be reproduced with an intensity corresponding to its distance from the source of the sound. If the actor

is on the right of the stage, the sensation transmitted to the right ear, we may conclude, will be stronger than that transmitted to the left ear. Should the actor change his position, the sound also would change, and it would then be the turn of the left ear to be more strongly impressed. The result of these changes is to give the listener an idea of the respective positions of the singers on the stage, and of their movements; and thus a listener is led to feel as if he were present at the representation, but with his eyes shut.

The success of this device was great; but the laying down of such

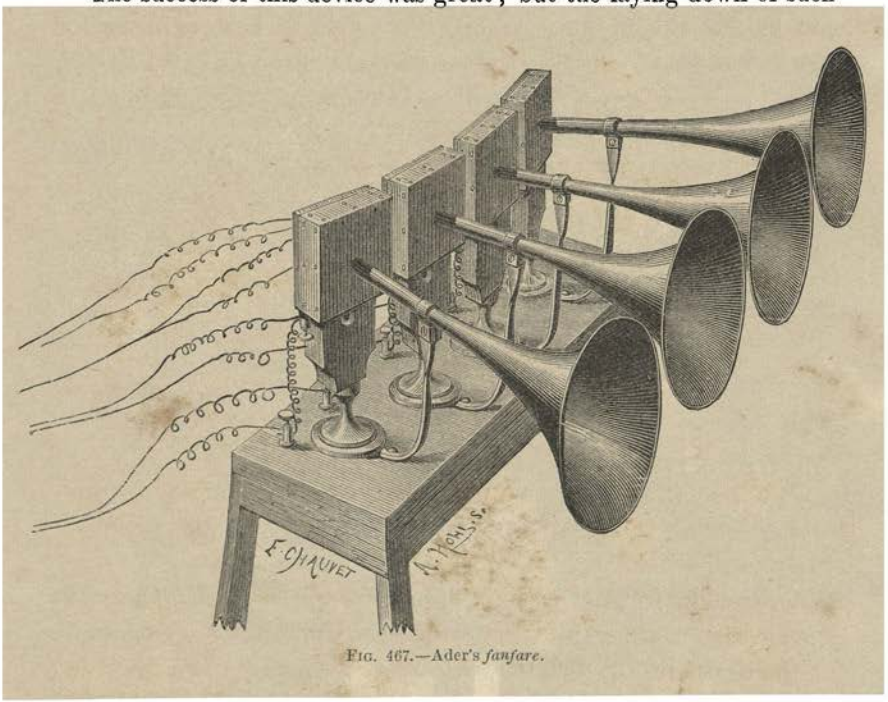

FIG. 467.—Ader's *fanfare*.

numerous wires was very expensive,[1] and we doubt whether it excited any other interest than curiosity. Whatever perfection may be arrived at with regard to faithfulness of transmission of instrumental and vocal sounds, hearing by telephone will never compensate for the absence of the scenery and the actors, their gestures and faces, and will never have that particular charm which comes from the association of all the attractions comprised in a musical or dramatic representation. Concerts of instrumental music perhaps alone escape

[1] It appears that the telephonic installation cost 160,000 francs (£6,400).

the *ennui* of a blind and solitary hearing. These reservations on the future of this special application of the telephone ought not, however, to diminish at all our admiration for the perfection with which the problem of the transmission of the sounds and voices of an orchestra —and of such an orchestra as that of the Grand Opera—has been solved.

We shall also refer to another application of microphonic apparatus to the reproduction of musical airs. We mean the arrangement devised by Ader at the Electrical Exhibition of 1881, and by the aid of which visitors were able to hear, in all parts of the Palais de l'Industrie, a trumpet *fanfaronade* executed by four

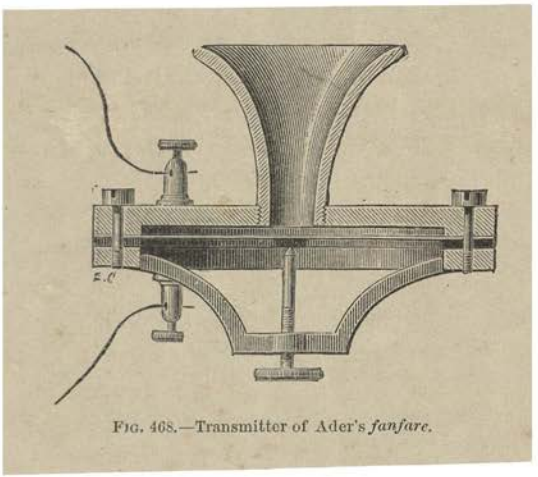

FIG. 468.—Transmitter of Ader's *fanfare*.

performers in front of a transmitter of a special form. The whole combination of apparatus constituted what was called Ader's *fanfare*.

As shown in Fig. 468, the transmitter is composed of a telephonic mouth-piece furnished with a strong diaphragm, in the centre of which is fixed a disk of platinum, making contact against a point of the same metal mounted upon a support and with a screw adjustment which can be regulated at pleasure.

The four receivers are ranged, as shown in Fig. 467, in the arc of a circle, and are each composed of a trumpet emerging from a case, the inside of which, opposite the opening of the trumpet, encloses a very thin plate of pine-wood, L L (Fig. 469). Behind this plate a horse-shoe magnet, A A, bears two small pole-pieces of soft iron, affixed to the ends of the poles; upon these pole-pieces are coiled wires that

form part of the telephonic circuit. In the space between the coils, almost in contact with the projecting pole-pieces, is a little piece of soft iron, *a*, supported upon a wooden peg, *t*, itself attached firmly to the centre of the pine-wood diaphragm. When the transmitter works, the fluctuating currents set up in the magnet variations of

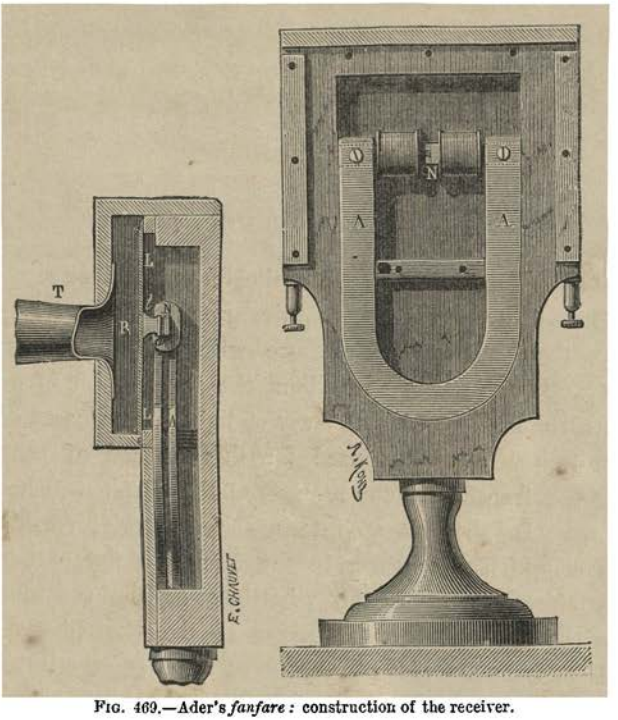

FIG. 469.—Ader's *fanfare*: construction of the receiver.

magnetic intensity, and these cause the little iron armature to be rapidly drawn to and fro, thereby throwing the whole diaphragm into vibration. These vibrations, which correspond in pitch to the original trumpet sounds, are very energetic. They set up air waves which, as they are given forth from the mouths of the four trumpet mouth-pieces of the receiver, have all the fulness of the sound of hunting horns.

CHAPTER VIII.

THE RADIOPHONE.

§ 1.—*Graham Bell's Photophone.*

SCARCELY had Graham Bell received from the Institute of France the great "Volta Prize," on the ground of his telephonic inventions, than he enriched science with a still more wonderful discovery. It was nothing less than the transmission of musical or articulate sounds by means of a ray of light. The name *photophone* is given to the apparatus used for this method of transmission. Between the transmitter and receiver of the telephone, whatever the system may be, there is an intermediate material conductor, the function of which is to carry, in the form of a fluctuating or undulating electric current, the vibrations of the sonorous waves. Between the transmitter and receiver of the photophone no such material conductor is used: a beam of light is substituted for it. Sound can consequently be transmitted through empty space (void of ponderable matter), since light-waves are propagated through the ether of space. Since the discovery of the photophone was announced, the principle on which it rests has been enlarged; it is now proved, as the inventor himself conjectured, that the invisible waves of radiant energy are endowed with the same power as luminous waves. For this reason, and by common consent, the name of *radiophony* has been given to the whole of the phenomena by which this power is manifested.

Bell was led to the invention of the photophone by studying the curious properties of the element *selenium*, a rare metal discovered sixty years ago by Berzelius. This body is a conductor of electricity, both when it is melted (at 210° C.), as Knox proved in 1837, and at

ordinary temperatures, when in the special allotropic state described in 1852 by Hittorf. Of dark-brown colour, almost black by daylight, and very brilliant when in a vitrified state, freshly melted selenium is red and transparent when in thin films. Its vapour is also red. In order to anneal it, it is kept for some time hot, but below its melting-point, it then takes a granulated form, crystalline, and of metallic appearance, closely resembling plumbago. This latter variety of selenium is a much better conductor of electricity than the black, fused, unannealed variety. But its conductivity is very variable, as Willoughby Smith found while experimenting on pieces of selenium such as were used as resistances in submarine cable work. He discovered in fact that in this curious substance the resistance which it offers to the flow of electricity through it is diminished when it is exposed to light. The discovery of this property was the starting-point of the researches of Adams and Day, and of many others who studied the conductivity of selenium by the aid of the galvanometer. The idea then occurred to Bell to substitute a telephone receiver for the galvanometer, because its sensitiveness is so much greater. In studying the question he says he saw that he ought to proceed differently from the way in which previous observers had done: first, because the causes of the sound in the telephone receiver being analogous to those which electric induction produces, you can only obtain, by varying the resistance, effects when the electric current employed passes from a stronger to a feebler state, and *vice versâ;* and in the second place, because the total effect is proportional to the differences in the strength of the current. It was then evident to him that the telephone could only respond to the effect produced in the selenium at the moment of its passage from light to darkness, and *vice versâ;* and that, to obtain results more susceptible of being heard, it was necessary to multiply these luminous changes, making them occur sufficiently rapidly to give rise in the receiver to sonorous vibrations; in a word, it was necessary to render the exposure to the light intermittent. He had remarked previously that solitary vibrations, so feeble as to be imperceptible in the telephone, became appreciable when repeated with a sufficient frequency. He was then struck with the idea of producing sounds under the influence of light; and, while studying the question more deeply, he thought that all the effects of transmission of sound

produced by means of electricity might be obtained by the changes of intensity of a luminous ray projected on selenium, and that they would only have as their limit that which limits the action of light on this substance. Now, as is well known, a beam of light can be sent many miles in a straight line by proper concentration with a parabolic mirror: hence arose the idea that it would be possible to establish by this means telephonic communications from one point to another without the need of any conducting wire between the transmitter and the receiver. To render this idea practicable it was evidently necessary to construct an apparatus susceptible of being acted upon by light under the influence of spoken words; and so he was led to the system of which we are speaking. We shall now see how Bell carried out this conception. His experiments were numerous, and the apparatus was varied in many ways; we shall confine ourselves to

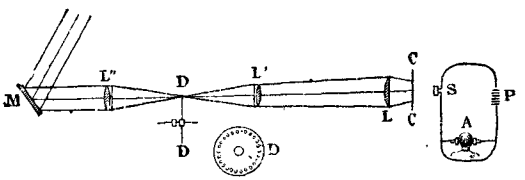

FIG. 470.—Bell's musical photophone.

describing the two forms of the photophone that go by the two following names: the *musical photophone* and the *speaking photophone.*

In Fig. 470, M is a flat mirror on the surface of which a parallel beam of light, such as sunlight, is thrown. The rays of this beam, after having been reflected, are received by a lens, L'', and concentrated to a focus, D. After crossing at this point, the rays are received by a second lens at the same focal distance as the first, and are again rendered parallel. A third lens, L, placed at a great distance, projects them upon a plate of selenium, S, interposed in the circuit containing a battery, P, and a pair of telephone receivers. In order to vary rapidly the intensity of the beam of light, there is placed at D a disk pierced at its circumference with a certain number of holes, like the disk of a phenakistiscope. The disk is placed perpendicular to the axis of the lenses, and so that the focus D coincides with one of the holes. If then there is given to the disk a more or less rapid movement of rotation around its

axis, the light will pass every time one of the holes comes to D, but will be intercepted by the portions of the disk that lie between the holes. The number of interruptions of the beam of light will therefore be as frequent as the number of holes that pass; and this in turn depends on the speed of rotation given to the disk. Let us suppose that there are forty holes in the disk, which is being turned at the speed of twenty-five revolutions a second: the number of interruptions to the beam of light will be one thousand per second. An equal number of variations in the conductivity of the selenium plate, and consequently in the strength of the current which traverses the telephonic circuit, will be occasioned, and therefore there will be given to the diaphragms of the receiving instrument the corresponding number of one thousand vibrations per second. Thus the

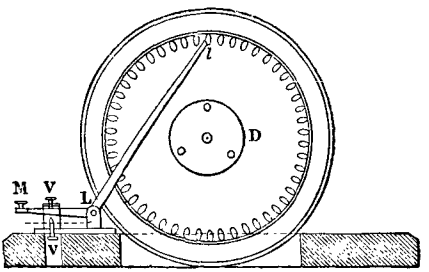

FIG. 471.—Disk of the musical photophone, with signalling lever.

person listening at A will hear a musical sound, the pitch of which will be proportional to the speed of rotation of the disk.

The photophone which we have just described is not, strictly speaking, a transmitter of sonorous vibrations. It is the light itself which sets up or creates these vibrations by its intermittences, in consequence of the influence which these intermittences exercise on the electric conductivity of the selenium. But Bell showed that it was possible in this way to utilize the musical photophone as a transmitter of a regular code of signals. For this purpose, by the side of the rotating disk, he places a bent lever (Fig. 471), which works like a Morse key. The shorter arm works between two stops, V V, while the other arm is so placed that its upper end moves across that hole in the disk through which the light streams. When the lever is in one position the light is intercepted, causing

an interruption in the sounds of the receiver. On depressing the lever at M the light is no longer stopped and the telephone sounds.

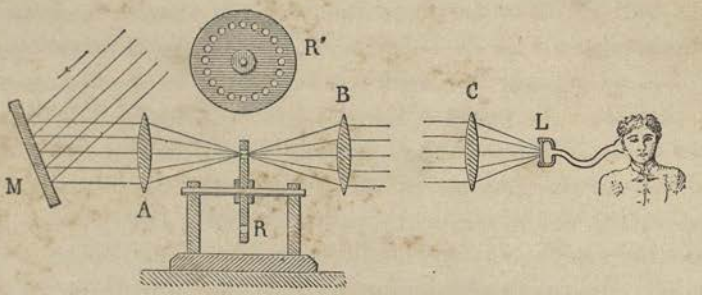

FIG. 472.—Bell's experiments with the musical photophone.

According as the stoppage is more or less prolonged, depending on the working of the key, short or long sounds separated by intervals

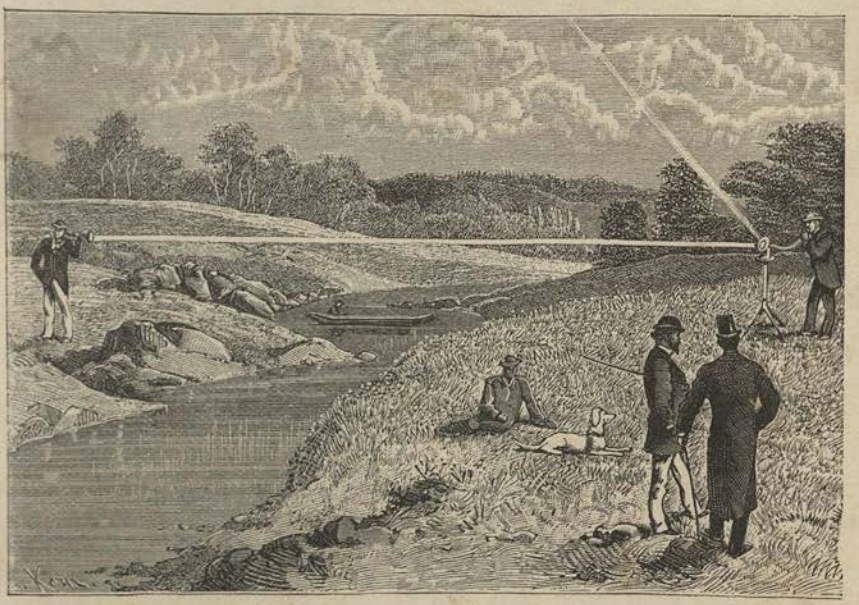

FIG. 473.—Bell's photophonic experiments.

of silence are obtained; and thus all the signals of the Morse alphabet can be transmitted and a telegraphic correspondence carried on.

Instead of causing the intermittent luminous rays to fall on selenium, Bell tried their action on several other substances in the form of thin plates: thus he experimented on gold, silver, platinum, iron, steel, brass, copper, zinc, lead, antimony, German silver, Jenkin's metal, Babitt's metal, ivory, cellulose, gutta-percha vulcanite, flexible india-rubber, paper, parchment, wood, mica, and silvered glass. Of all these substances vulcanite gives the best results, and the most distinct sounds; antimony, paper, and mica gave the feeblest sounds. Fig. 472 shows how these experiments were arranged. The listener used a hearing tube fitted to a capsule, having as a diaphragm the thin plate that was to be experimented upon.

We now come to the speaking photophone. In this apparatus, the transmitter is necessarily modified, since the vibrations of the voice which are to be transmitted must be made to vary the

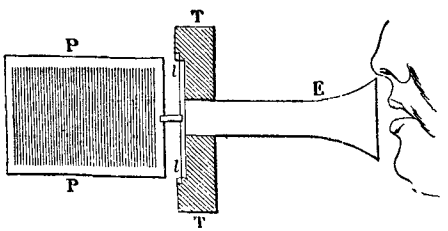

FIG. 474.—Photophone: first kind of transmitter.

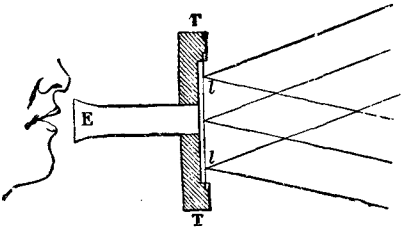

FIG. 475.—Photophone: mirror transmitter.

luminous rays in a manner that corresponds to the fluctuations of the sound waves.

In Fig. 474 is seen the first kind of transmitter tried by the inventor. It is a simple telephonic box, T T, furnished with a mouth-piece, E, and a vibrating plate, L L. Fixed to the latter is a movable plate, P P, pierced with slits. Another similar plate is placed behind it in such a position that the slits correspond exactly when the apparatus is not working. Luminous rays can then traverse the perpendicular slits in the two plates. But if the vibrations of the voice act on the diaphragm, corresponding movements will be imparted to the movable plate which is attached to it. Hence will arise extinctions, or modifications more or less marked, in the intensity of the luminous rays, which in their turn act on the selenium of the receiver, and on the electric currents in the telephonic receiving circuit, arranged as previously described.

This first crude arrangement was soon abandoned, and the following was substituted. The form of the transmitter is the same as the preceding one; but the diaphragm (Fig. 475) is a thin plate of silvered glass, or mica, *l l*, constituting a mirror on which fall the rays from a powerful luminous source, such as an electric light, or, better still, the sun. Reflected from the surface of the mirror L (Fig. 476), the luminous beam, after having traversed a lens, B, which renders the rays parallel, is directed on to the receiver. This second part of the photophone is formed of a parabolic mirror, M, of silvered copper, about 70 centimetres in diameter, at the focus of which is fixed the sensitive selenium apparatus S, which communicates with the telephonic circuit. A special form is given to this portion of the apparatus, for, owing to the high specific resistance of even the annealed selenium,

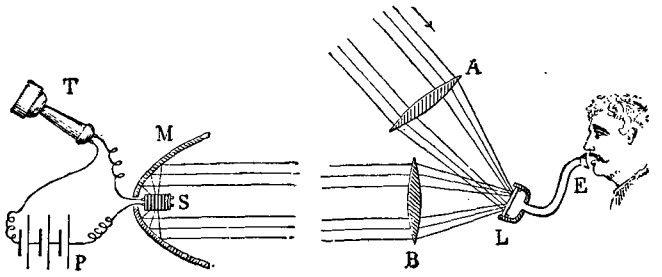

FIG. 476.—Path of the beam of light in the speaking photophone.

it is necessary to employ an arrangement in which, while a large surface is exposed to light, the electric current will only have to traverse a short length of this peculiar substance. A series of brass disks are separated by disks of mica, rather smaller in diameter; the whole being made up in the form of a cylinder, the exterior surface of which presents a series of circular parallel grooves. The disks are connected up alternately in two series like the alternate plates of a condenser; and the interstices are filled with selenium. The surface is thus considerable, while the electric resistance is small. The current has then only to flow from any one of the brass disks through the narrow band of selenium to the next adjacent disk. Every time the light, reflected by the parabolic mirror, strikes the surface of the selenium, its electric resistance is

diminished, and the diminution is roughly proportional to the intensity of the luminous rays. Now we can see what happens when words are spoken into the mouth-piece of the transmitter. The luminous rays, which, when the mirror-diaphragm was at rest, were reflected without variation in their intensity, are now modified in consequence of the changes of figure which the vibration of the voice impress on the surface of the reflecting plate. The mirror, in fact, when spoken to bends slightly in and out, and scatters or concentrates the beam of light in rapid alternations. Hence there

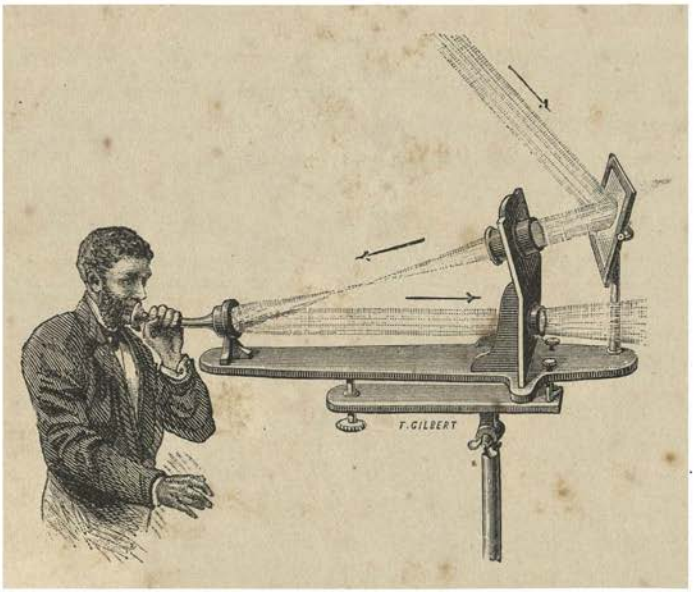

FIG. 477.—Bell's photophone; the transmitter.

arise variations in the amount of light that falls on the selenium corresponding to the variations of the sonorous waves, and these variations cause the current in the telephonic circuit to vary.

The photophone produces with great clearness either spoken words, or airs and musical songs. In one of the first experiments made with the apparatus constructed as we have described, Mr. Tainter—whose name should be coupled with that of Bell, whose collaborator he was in most of these experiments—had charge of the transmitter placed at the top of the Franklin School at Washington, and Mr. Graham Bell was at the receiver in his own laboratory some 250 yards away. On

placing the telephonic receiver to his ear, he distinctly heard the following words transmitted by the projecting apparatus: "If you hear what I say, come to the window and wave your hat." In their laboratory experiments the receiver and transmitter were always so far distant from each other that no sounds could reach the ear directly, and they had at first placed the receiving telephones in a different room from that in which the plate of selenium and the projecting system were situated. They proved that words could be reproduced with oxyhydrogen light, and even with that of a kerosene lamp.

FIG. 478.—Bell's Photophone; the Receiver.

After having repeated at Paris, in October 1881, his experiments with the articulating photophone, Bell presented his beautiful apparatus to the Académie des Sciences through M. Breguet, who, acting as interpreter, repeated the experiments, using the beams of the electric light. This demonstration was received with great enthusiasm by the learned audience, as indeed it deserved to be.

And now what is the future reserved for the photophone? What practical importance will this new method of communication have? Has the telephone to fear competition from the photophone? That is hardly probable. The distance at which the new apparatus works

at present is very small, even when the sun's light is employed; besides, it is indispensable that the transmitting and receiving stations between which the beam of light travels, should be in a direct line and separated by no obstacle. The advantage which the photophone has over the telephone consists principally in the absence of intermediate conductors, which are always costly. This advantage is balanced by the short distance, an inconvenience, however, which would disappear if means could be found of establishing relays from point to point. In mentioning the possibility of employing mirrors to turn the beam of light at each relay, Breguet justly remarked that successive reflections would absorb a notable fraction of the light and thus reduce its intensity. In special circumstances, such as in military operations and sieges, the services now demanded from the heliograph might perhaps be obtained from the photophone.

Although it is still doubtful whether this novel apparatus is of any practical utility, there can be no doubt about the great theoretical and scientific importance of the discovery of the radiophone. As we cannot enter here into all the recent developments, we shall limit ourselves to mentioning the results of some remarkable researches made in this new branch of science by M. Mercadier, with the help of the apparatus represented in Fig. 479. The first conclusions relate to the sounds produced under the direct influence of intermittent rays of light:—

"(1) The radiophone does not appear to be an effect produced by the mass of the receiving plate vibrating transversely, like an ordinary vibrating plate. The nature of the molecules of the receiver and their mode of aggregation do not appear to exercise a predominant influence on the production of sounds.

"The radiophonic phenomenon appears to result principally from an action exercised at the surface of the receiver, and it is amplified when this surface is covered with substances like lamp-black platinum-black, and the like.

"(2) Radiophonic sounds result from the direct action of radiations on the receivers. Radiophonic sounds are produced principally by the undulations of great length of wave, called 'calorific.'

"(3) The medium in which radiophonic vibration is produced is the layer of condensed air on the surface of the receivers. This

layer of air, particularly when the surfaces are smoked, or covered with a substance absorbing heat, is alternately heated and cooled by intermittent radiations, with the result that periodic and regular dilatations and contractions are set up; hence a vibratory movement communicated to the adjacent gaseous layers, which also vibrate directly under the same influence.

"(4) Radiophonic sounds cannot be produced unless the medium which surrounds the receiving surfaces is gaseous. A liquid or solid medium cannot produce them; but a gaseous medium con-

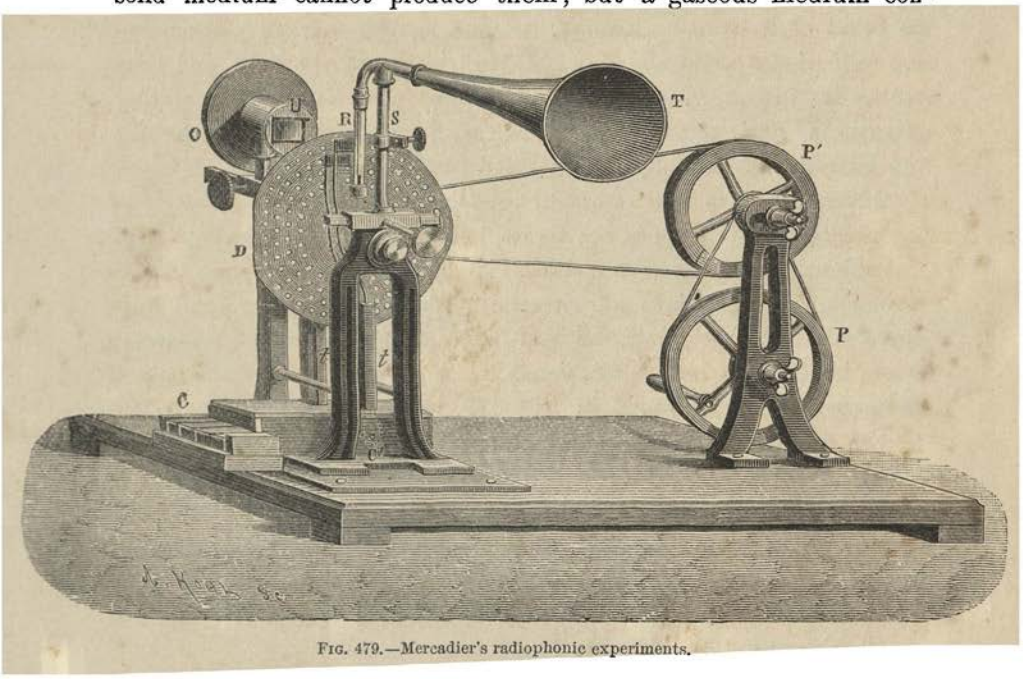

FIG. 479.—Mercadier's radiophonic experiments.

taining vapour, particularly vapour of ammonia or ether, develops them in a remarkable way: those vapours that have the greatest absorbing thermic power give out the greatest effects."

As for sounds produced under the influence of the variations of electric conductivity which characterize certain substances, such as selenium, when they are submitted to the intermittent action of rays of light, Mercadier shows that they are due to an action peculiar to light, not a thermic action. To demonstrate this, he substitutes for the receiver of Fig. 479, that represented in Fig. 480, which is a

receiver with selenium arranged in a new way to obtain a better effect.

We cannot, in closing this chapter, pass over an application of the laws of radiophony also due to M. Mercadier. We refer to a system of telegraphy for multiple and simultaneous transmission. The inventor gives to this system the name of "auto-reversible multiple electric teleradiophone." He says, "I give the name of teleradiophone to that system of electric telegraphy in which the signals are produced by radiophonic effects. This system also admits of the transmission by a conductor of many simultaneous signals, in one direction or the

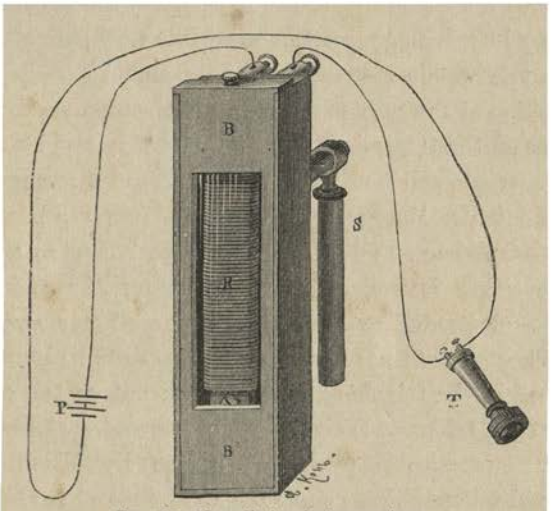

FIG. 480.—Mercadier's selenium receiver.

opposite, at will, hence the use of the adjectives 'auto-reversible; and 'multiple.'" Trials made by the author of a system of this kind have already given good results.

Simultaneous Telegraphy and Telephony.

A somewhat surprising feat in electrical communication is the use of a telegraph line for the transmission of telephonic messages at the same time that the ordinary telegraphic despatches are being transmitted through the same line. This feat was first accomplished

in 1878 by Mr. George Black and Dr. A. Rosebrugh of Toronto ; who showed that if the telephonic instruments were connected to the lines at each end through a small condenser to earth, the two telephones can communicate with one another ; and their presence does not in the least affect the working of the telegraph ; whilst the ticking noises of the telegraph do not much interfere with the transmission of speech by the telephones. A few years later the same problem engaged the attention of a Belgian electrician Mr. Van Rysselberghe, who sought to improve this suggestion by so modifying the telegraphic service as to get rid of the ticking sounds that are heard in the telephones. This he accomplished partly by the aid of condensers and partly by introducing electromagnets into that part of the circuit where the telegraphic instruments are situated. The great self-inductive action of the coils of wire in an electromagnet produces a double effect on the transmission of signals. The rapid and delicate telephonic currents will not pass through the electromagnet to any appreciable extent. Moreover the very same property has the effect of retarding the rise and fall of the electric currents, so that though the signalling key is worked by the operator the sudden application of the electromotive force does not result in a *sudden* rise of current. The currents neither start nor stop suddenly, and so the ticking sound in the telephones is obviated; but on the other hand the speed of the telegraphic signalling is retarded. It has therefore been found inpracticable to introduce Van Rysselberghe's device into the rapid telegraphic service, such as is required in Great Britain by the necessities of commerce.

The Air Telegraph.

An American electrician Phelps conceived the idea of telegraphing to a train whilst in motion on the railway. This he successfully accomplished by taking advantage of the inductive effects which charges of electricity can exercise at a distance across a layer of air. But the result, though highly interesting as a feat of telegraphy, has not proved as yet of any commercial importance.

The Phonopore.

This invention, due to an English electrician, Mr. Langdon Davies, is of great interest, and probably will prove of great importance during the next few years. The group of inventions comprised under this name comprises a system of multiplex harmonic telegraphy, a vibratory telegraph which can be duplexed or diplexed upon any ordinary telegraph, and system of simultaneous working of telegraphs with telephones upon the same line.

The essential feature of the phonopore system is a peculiar instrument or apparatus of very simple construction which, whilst utterly inpervious to the passage of ordinary electric currents, permits of the passage (by a species of induction) of rapidly-alternating, or undulatory currents. This apparatus consists simply of two perfectly insulated copper wires many feet in length, wrapped side by side upon a bobbin. Two of the ends of the wires are insulated, the other two ends being used for the circuit. An electric current attempting to flow in through the end of one of the wires finds no passage out, the other end of the wire being insulated. Only enough current can flow in to charge the wire, but in so doing it sets up two effects. It can, by influence, set up an opposite charge on the neighbouring wire; and it can also while flowing in act inductively upon the neighbouring spiral, in the same way as the primary current in an induction coil acts upon the secondary circuit. The simple *phonopore* then possesses not only capacity like a condenser but also mutual induction like the induction coil. To this peculiar combination of properties it owes its remarkable adaptibility to the problems of simultaneous and multiplex telegraphy. When a simple phonopore is applied, as the condenser was applied by Black and Rosebrugh for superposing telephones upon the telegraph line, it is not found needful to deaden or retard the telegraphic signals by the additions of electromagnets or condensers to the signalling apparatus; and the phonopores are less liable to be damaged, than condensers are, by atmospheric discharges. In the phonopore telegraph systems the signals are made by a vibratory apparatus which somewhat resembles the vibratory apparatus of the Ruhmkorff induction coil, and thus

rapidly alternating currents are generated at the transmitting station; the duration of such currents depending on the length of time that the key is depressed by the operator. Such rapidly alternating currents do not affect the action of any ordinary telegraphic instrument, and indeed will not pass through the coils of the electromagnets of ordinary telegraphic sounders, printers or relays. They are received at the distant end of the line by special receivers which are interposed in a branch circuit, which also includes a phonopore, between line and earth. These special receivers are of several kind. Some are simple acoustic receivers, resembling those of the ordinary telephone. Some are harmonic, containing a vibratory organ such as a tuned steel ribbon, or a tuned reed, which can only vibrate in response to impulses transmitted from a corresponding reed in the transmitter. These tuned ribbons or reeds actuate a sort of delicate relay which in turn sets in operation an ordinary sounder or printer. In the harmonic multiplex phonopore telegraph, two, three, or more sets of instruments are fixed upon the same line, having the reeds or ribbons tuned to separate notes, each receiver being tuned to the same note as its corresponding transmitter. In the vibratory duplex phonopore service, simple vibratory phonoporic telegraph instruments are merely connected to the same line upon which ordinary telegraph instruments are working. Each works in perfect independence of the other, and each may be duplexed in itself; that is to say, the ordinary telegraph may be duplexed in the ordinary way, and the phonopore telegraph may be duplexed in itself by the use of differential windings; and thus there is constituted a quadruplex service far more simple and reliable than the complicated quadruplex methods previously in use.

CHAPTER IX.

ELECTRIC CLOCKWORK.

§ 1.—*Electric Chronometers.*

THE rapidity with which electric currents are propagated, and the possibility of simultaneous movements being produced in two pieces of mechanism far distant but connected by a conducting wire, have suggested the application of electricity to horology. The synchronism of these movements makes it possible to keep any number of clocks going in perfect agreement at considerable distances apart, as for example in the different stations along a railway line. That is the first problem that has been solved, and the systems invented for that purpose have been a long time at work on railways, or in towns where public clocks are to be regulated. It is sufficient to put each of these clocks in electric communication with one regulator, consisting of a clock whose movement is controlled by electricity. Apparatus of this latter kind are called *electric clocks*, whilst the pieces of mechanism used to transmit the motion of an ordinary regulator to the distant clocks have received the name of *electro- chronometric counters.*

Electricity is also used to unite a number of clocks, each having separate motions and mechanisms, so as to establish agreement between them. This seems to be the most practicable application of electricity to horology.

Electro-chronometric counters, like all telegraphic apparatus, consist of two distinct parts. First, the *indicator*, or mechanism joining the regulating clock, whose function is to make and interrupt periodically, at regular intervals, the current from the battery, or other electro-motor. This current drives the receiving apparatus—that is, the

mechanism that moves the hands of each clock; take, for example, Garnier's counter. The regulator is an ordinary clock, which makes and breaks the battery circuit. The last member of the ordinary train of wheelwork bears on its axle a little mill *m* with four teeth. As this rotates, it alternately raises the knob *d* of the lever *l*, and lets it fall. In the first case, as in Fig. 481, the + and − poles of the battery communicate through the contact of two metal levers *t* and *l* closing the circuit, and the current passes. In the interval between two teeth the lever *l* falls again, contact ceases, the circuit is broken and the current stops. The two contact pieces are made of gold, or an alloy of platinum and gold, to prevent oxidation by the spark on making and breaking circuit. The essential parts of the

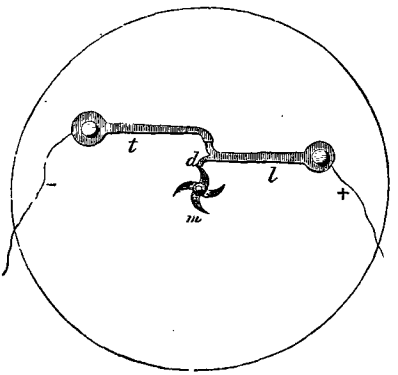

FIG. 481.—Transmitting mechanism in Garnier's chronometer.

indicator in Garnier's chronometer are shown in Fig. 482. As the regulating clock makes or breaks the battery circuit, the armature of the electro-magnet EE, is attracted or released, and thus raises the lever LL, by the rod *t*. The catch *c* on one of the ends of this lever on being raised, pushes forward a tooth of the wheel R. Two stops *b* and *b'*, prevent this wheel from advancing or going back more than one tooth. When the current is broken, the armature falls on the screw supported by one of the coils as seen in the figure; the lever LL falls down, and the catch *c* engages the following tooth, which it moves when the current excites the electro-magnet, on the circuit being again closed.

From the wheel R the motion is transmitted by convenient

mechanism, to the axles which move the two hands on the dial. The regulating clock and indicator being once arranged to work together continue to do so as long as the current from the battery is sufficient to attract the armature.

Two thick metal wires AB, CD (Fig. 483), from the battery P, are

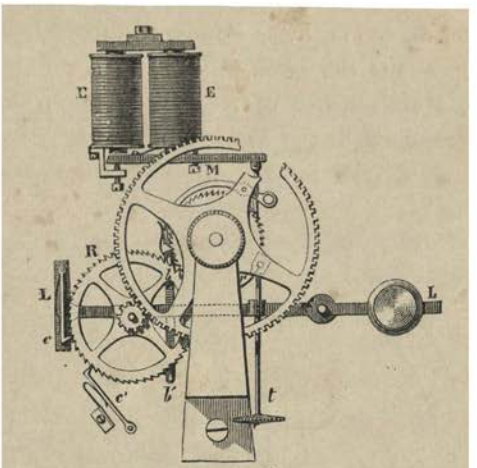

FIG. 482.—Indicator in Garnier's chronometer.

joined to the standard clock H. From these, other pairs of finer wires $a\ b$, $a'\ b'$ are taken to the indicators O, O', O'' etc. In this way there are as many branches off the main circuit as clocks, with independent communication to each of them. It is also possible to have wires branching off

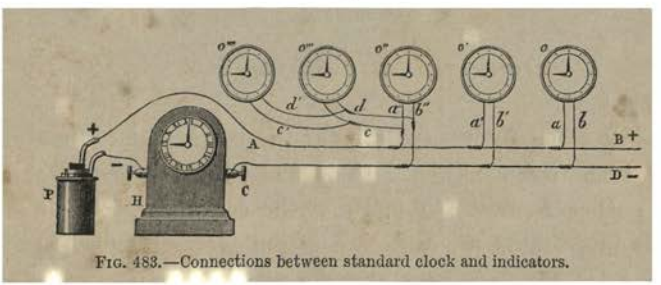

FIG. 483.—Connections between standard clock and indicators.

like $c\ d$, $c'\ d'$, to one or two indicators as O''', O''''. In Garnier's counter it is the weight of the armature which acts as the opposing force, with the result that this apparatus can only work fixed in a vertical position. The advantage lies in this force being constant, which is not the case when the force is due to the elasticity of springs.

In Froment's system the regulator was, originally an ordinary clock with a cog-wheel, the cogs of which slightly touched a fixed spring every second. This spring was a thin gold plate connected to one of the poles of a battery, the wheel itself being connected electrically to the other pole; thus there was a make and break of the current every second. Latterly Froment has substituted an electric regulator for the ordinary standard clock.

Fig. 484 represents the arrangement of the counter or indicator. The armature, M N, consists of a copper arm, O N, joined to a system of levers, S P Q N, the arms S Q, Q N tending to lie in a

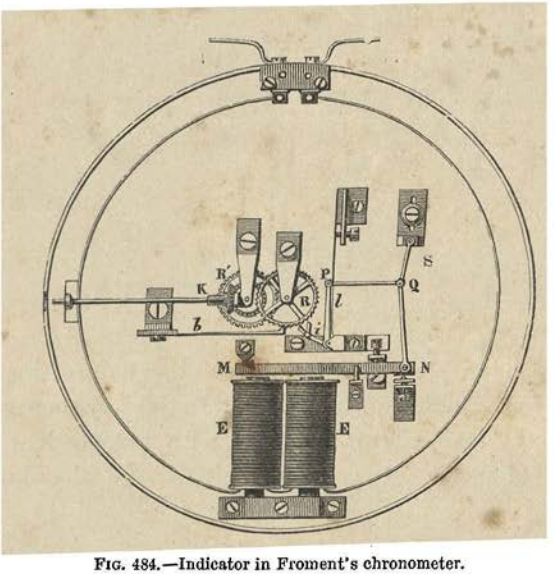

FIG. 484.—Indicator in Froment's chronometer.

straight line when by the passage of the current the armature is attracted. The rod, P Q, then acts on the jointed lever P *i*, and the catch, *i*, pushes forward one tooth of the cog-wheel, R. When the current is interrupted, the armature is pulled back by the spring, *l*, the arms, S Q N, are again bent, and the wheel is left free. The catch, *b*, prevents any backward movement.

The motion is communicated to the indicating hands of the apparatus by the pinion on the wheel, R', and the gearing of the bevel wheel allows the hands to be set at the hour by means of the rod, K, which has a square end on the circumference of the dial.

The original point about Froment's counter consists in the employment of the linkwork, S P Q N as an equalizer. This is intended to adjust the resistance to the attractive force of the electro-magnet on the armature. This pull is greatest when the distance of the armature is least, that is at contact: therefore at this instant, when the motion of the pieces is quickest, it would be suddenly stopped and thus injure the mechanism. However by the above arrange-

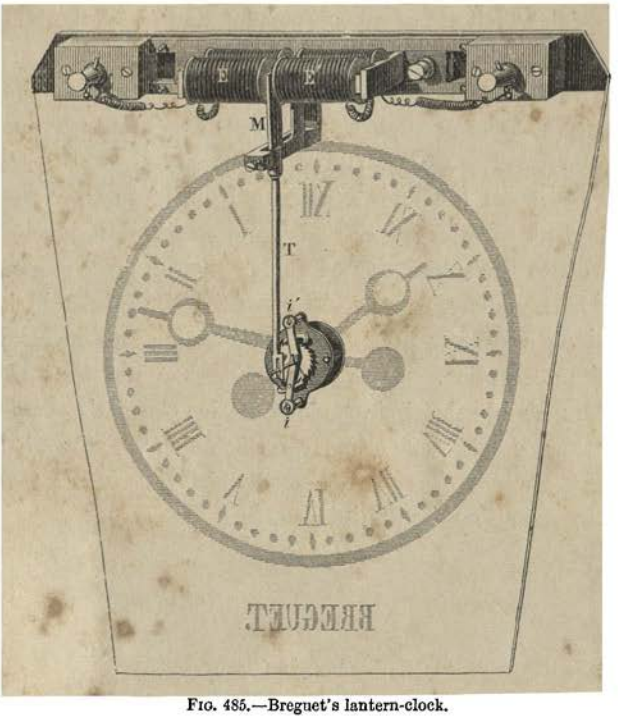

FIG. 485.—Breguet's lantern-clock.

ment the resistance increases at the same rate as the attraction, so that the motion due to the electro-magnet is equalized.

The electric chronometers of Bain, Breguet, Robert Houdin, and Nollet, are all worthy of note. At Paris, Lyons, Marseilles, Brussels, Ghent, and Leipsic chronometers on these different systems have worked, and are still working, and making known the time with regularity, and agreement in various parts of these towns.

Lantern-clocks are simply gas lamps inside which clocks are arranged, with dials on one or two sides. Nollet at Ghent

Detouche at Paris, and Breguet at Lyons have constructed apparatus of this kind. Fig. 485 represents one of the twenty-four lantern-clocks installed by Breguet at Lyons. There are two electro-magnets, E E', with their unlike poles opposite and facing so that the armature, M, which is magnetized, is at the same time attracted by one and repelled by the other, and inversely as the current circulates in one or other of the electro-magnet coils. The rod, T, attached to the armature, acts by a fork furnished with a pin, on two catches, *i i'*, which act as an escapement, and move the teeth of a cog-wheel, whose axle carries the minute hands.

In order that all electric chronometers may work with constancy and regularity, it is clear that watchfulness and care are necessary. Evidently the good state of the different parts, of the standard clock, and above all the maintenance of the battery, are necessary conditions. But as, after all, one of them may fail, it is clear that what constitutes the superiority of an installation of this kind over ordinary clocks, namely, the agreement of all the clocks in a large town, or along a railway line, would become a grave inconvenience in case of interruption. It is important then not only that the chronometers should be independent, as in Garnier's system, but also that they should not be driven by one regulator alone: by dividing a town into districts, each of which possesses a regulator, the above inconvenience is diminished.

§ 2.—*Electric Clocks.*

It is well known that the motive power of clocks is borrowed either from a raised weight or a spring, and that the pendulum serves to regulate the motion communicated to the wheel-work. The regularity of the motion depends on whatever drives the pendulum, which should be as invariable as possible. The motion of the pendulum is also kept up by the reaction of the escapement.

The problem which the inventors of electric clocks have tried to solve consists in giving the pendulum, directly, and without employing a motor and ordinary wheel-work, an electrical impulse calculated to continue and regulate its motion. One of the oldest

clocks intended to fulfil this condition is represented in Fig. 486 and is due to an able watchmaker of Beauvais, Vérité.

The pendulum, B, suspended by a spring, has attached to it a rigid transverse bar, A D, with two knobs which move freely inside two metal bells C and C′. These are suspended by very fine silver wires furnished with counter weights *p p*, from a horizontal beam insulated in the middle by a piece of ivory. Two electro-magnets E and E′, have their poles placed opposite two armatures of soft

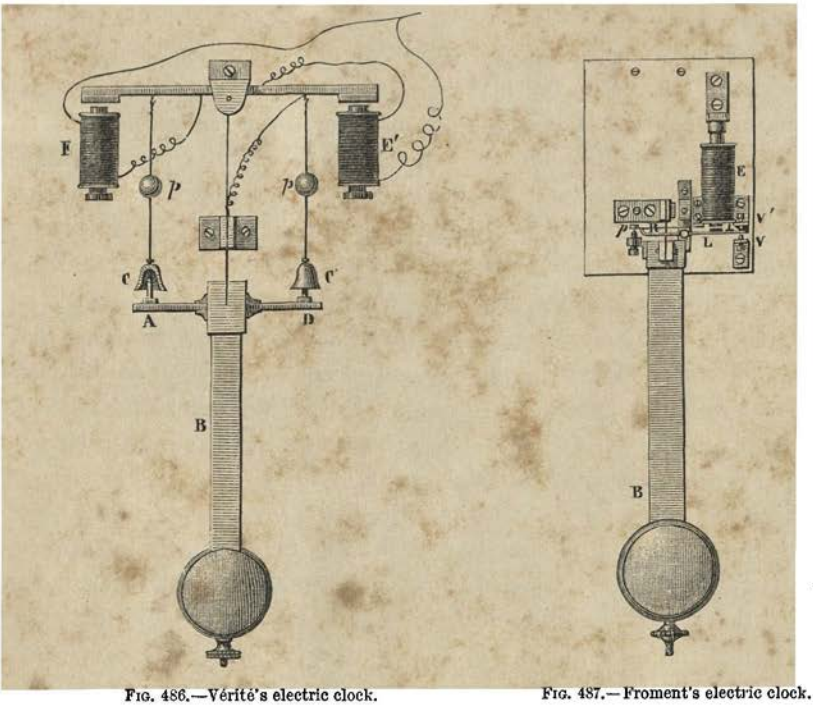

FIG. 486.—Vérité's electric clock. FIG. 487.—Froment's electric clock.

iron fixed to the beam, and their coils are in metallic connection with the corresponding arm of this beam, and on the other side with one of the poles of the battery. The other pole is joined to the suspension of the pendulum.

When at rest, the pendulum occupies a vertical position, and the knobs on the transverse bar AD are not in contact with either of the bells. But contact takes place with one of them, the one to the right, for example, when the pendulum is moved towards

the right. By this contact the circuit is closed, and the electro-magnet E′ being excited attracts the right-hand arm of the beam. The bell C′ goes down, and by its weight on the knob gives the pendulum an impulse, causing it to make a backward movement. This movement separates the knob from C′ and thus breaks the circuit. But the pendulum, moving towards the left, brings the left knob into contact with the bell C, and the circuit is closed on this side; the electro-magnet E pulls the left arm, and in its turn the bell C presses on the arm A of the tranverse bar on the pendulum, and so on.

Froment's electric clock receives a periodic motion from a little weight p (Fig. 487) which rests on a side screw every time that the circuit is closed. The pendulum B has a spring suspension and is in direct communication with the positive pole of the battery. The other pole is connected to the electro-magnet coil E, which communicates with a spring plate, having the weight p soldered on its end. One arm R of a lever R L supports this plate and the weight when the circuit is open; the other branch L bears an armature which is attracted by the electro-magnet every time the circuit is closed and the current passes. Now the circuit is opened and closed successively at each oscillation of the pendulum. During the one half oscillation towards the left, the screw touches the weight p; the circuit is closed, the armature attracted, and the arm R of the lever ceases to support the plate and weight, which then act on the screw, and consequently on the pendulum, giving it a backward impulse. Then contact ceases, the circuit is opened, the armature takes its original position and the weight ceases to act. Two screws V and V′ also limit the travel of the arm L of the lever. Thus the constant weight, acting at each oscillation, keeps up the motion of the pendulum.

Houdin's regulator is represented in Fig. 488. The suspension spring of the pendulum P is in communication with the positive pole of a battery at O′. The pendulum is furnished with two arched horns B and B′, which come alternately in contact with two spring plates, thus closing the circuit alternately through the electro-magnet coils E and E′

Let us suppose that the pendulum oscillates towards the right and that contact is then made by the arm B. The current in the wires, as indicated by the arrows, passes through E′; the left branch of the

armature AA, being attracted, raises the spring plate, which acts, by the rods t' l and the catch, on the cog-wheel so as to make it turn through the space of one tooth. The same movement raises the little mass l, and places the hook c' under the plate, which thus becomes caught, whilst the plate to the right is disengaged from the hook c, and can act by its weight during the backward motion of the pendulum. Then contact ceases, the current is interrupted, the

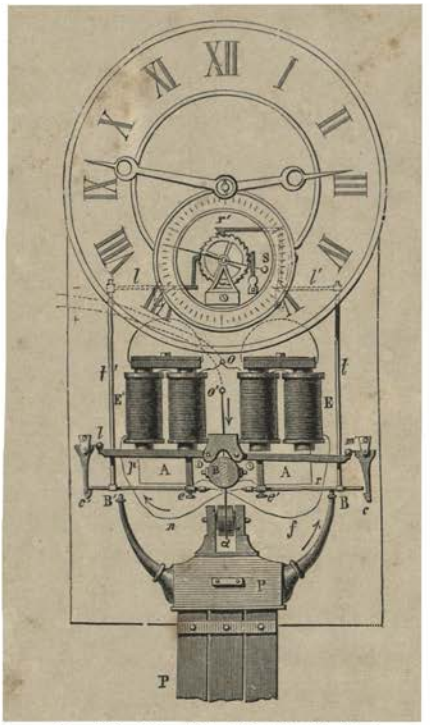

FIG. 488.—Robert Houdin's Electric Clock.

armature to the left ceases to be attracted, the rod t falls and pushes the corresponding catch over a fresh tooth of the cog-wheel.

When the pendulum moves towards the left it makes contact between B' and the spring plate on the left. The current circulates through the electro-magnet E, the armature on the right is attracted, and the same movements that we have just described are produced in the corresponding pieces placed symmetrically; so that this time it is the spring plate on the left that is free, and acts by its elasticity and

its weight on the arm B′ of the pendulum, and the catch r' in its turn will move on the cog-wheel the distance of one tooth. Two counter-

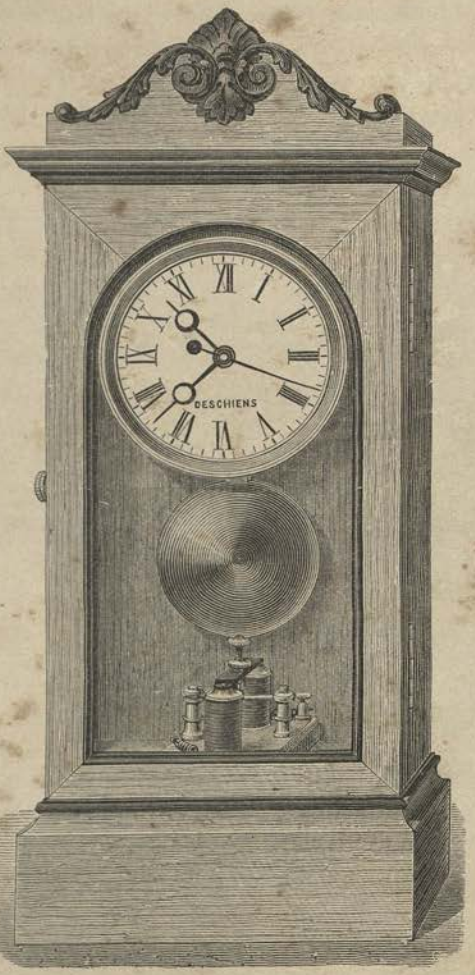

FIG. 489.—Hipp's Electric Clock; outside view.

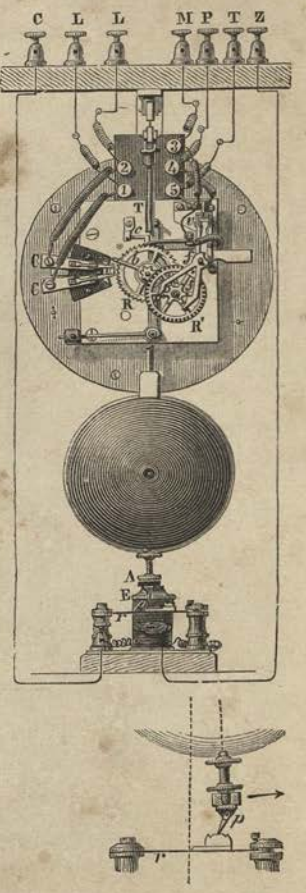

FIG. 490.—Details of mechanism in regulator and distributor.

poises e, e', which can be fixed at different distances along the spring plates, regulate the action of these plates and the pendulum.

Another very ingenious electric clock was invented by Hipp, a clockmaker of Neuchatel. Like the preceding ones, it can be

arranged to work alone, or to serve as a regulator or standard clock to a series of others electrically connected with it. The *regulator* consists of a train of wheels driven by an oscillating pendulum. Whilst the oscillations are of sufficient amplitude, electricity does not interfere. However if the amplitude diminishes, the current actuates an electro-magnet, and the impulse thereby given to the pendulum produces the motion needed to maintain regularity.

The following is the arrangement:—An electro-magnet E (Fig. 490), is firmly fixed underneath the pendulum, so that the line between the poles is a little to the one side of the rod in its vertical position. The pendulum carries an armature at A, which at each oscillation passes very close to the poles. Underneath, and at its end, a pallet *p*, or a little steel plate terminating in a knife edge, swings freely on a horizontal axis. At each oscillation of the pendulum this pallet moves with it, slides, but does not press on a raised piece called the stop, furnished with two notches and supported on a spring plate *r*, connected to the negative pole of a battery. When the pendulum has sufficient amplitude of vibration, the pallet goes over the stop; but if this motion slackens, it stops in the position marked in the lower figure, and at the beginning of the next oscillation the pallet catches in one of the notches. If the stop could not then descend, the pendulum would stop, but the spring plate which carries the stop yields, contact is made with the terminal of the other wire from the battery, and the circuit is closed. The electro-magnet being thus excited pulls the armature of the pendulum, and it is this attraction which gives the impulse necessary to keep up the motion of the pendulum. At the next oscillation, all goes on as formerly, and it is only when a new impulse becomes necessary that electricity comes into play. The interval of time between two successive impulses, called by Hipp the *duration of impulse*, depends on the battery power, it might be many minutes, or only a few seconds long. With one Leclanché cell, a regulator of this description will go without interruption for many months.

The function of the *distributor*, is to transmit the time of the regulator to any number of chronometers, electrically connected with it, and with the battery. The mechanism consists of a cog-wheel, R, with sixty teeth, which, at every oscillation of the pendulum, marks a second, and has on its axle a metal arm, *b*, which makes one turn

per minute with the wheel, and at a given moment touches one, two, or more pallets connected at C C to the line wires. A current is thus sent once a minute into each chronometer whose mechanism is controlled thereby. As this requires a periodic change in the direction of the current, the regulator carries a reverser, seen in detail in Fig. 490 at the right. A wheel, R′, moved by a pinion on the cog-wheel R, has pins on its spokes which rest on the arms of a forked lever, *f*, and make it oscillate round its point of support. Two spring plates, fixed to another arm of the lever, oscillate in this way round a mean position, and make contact with the positive and negative poles of the battery alternately. Electric clocks on Hipp's system work regularly in several towns in Switzerland.

The International Exhibition of Electricity in 1881 included a great many specimens of this new art; time pieces and electric clocks, counters, electro-chronometers, alarums, &c., abounded in the galleries of the palace. But, from a practical point of view, all these systems, which offered nothing very new, are surpassed by various systems adopted as regulators, for the distribution and regulation of time in public clocks, throughout the city of Paris.

§ 3.—*Electric Distribution of Time.*

Though the problem of electric horology has received a great many ingenious solutions, many of which do honour to their authors, still the use of clocks of this kind is not very general. We have quoted some examples of their application in the public distribution of time in cities; but in most places these systems are now abandoned. This has been caused by the difficulty of maintaining the batteries and electric communications always in an efficient state without the constant inspection which deprives the system of its principal advantage. The employment of electric chronometers, controlling all the indicators by a standard clock, offers the very serious inconvenience of agreement in any stops, or in all the errors of the central mechanism. As Niaudet rightly says, "If the regulator stops, or a battery cell ceases, or the wire breaks, the whole system stops. An awkward or mischievous person can easily deprive many

of knowing the time, or lead them into error. It is possible to find remedies for these defects, but still the objection exists."

The question of electric distribution of time in great urban centres, has been settled in another way. Electricity is used, but not to give movements to special mechanisms, nor even to correct from minute to minute all the public clocks by a current from the central regulator. In the new system which works well now in Paris, all the clocks necessary to be kept alike have independent movements. The *rôle* of the electric current from the regulating clock, placed in the Observatory, is to maintain synchronism between the pendulum of this clock and the motions of the pendulums of a certain number of regulators distributed in fixed centres in the principal quarters of the town. These regulators in their turn are connected electrically with clocks; for example, they send every hour a current whose duration is enough to correct those that go slow or fast, and to set them at that instant at the exact time of the Observatory, so that the deviation, in these intervals can never exceed the error due to the peculiar mechanism of each clock for one hour.

Some practical details may be given by taking as a guide the Report of Admiral Mouchez, the Director of the Paris Observatory, on the service of clocks in 1880. The directing clock arranged to give the second of mean time, is a Berthoud clock; this is daily regulated by an astronomer, either by reference to astronomical observations, or, in case of bad weather, by comparison of its indications with those of underground clocks "whose great precision and regularity are never doubted." The corrections of this clock are made by increasing or diminishing little movable weights placed in a cup fixed on the pendulum, as seen at P in Fig. 491. By adding a weight, the number of oscillations of the regulator per minute is increased; by taking one away, it is diminished.

Two other clocks are placed in the same room with the directing clock, with which they are electrically connected so that all indicate the second simultaneously. These two regulators control two circuits in the city, one the *west circuit*, the other the *east*, each of which contains a certain number of regulators, or time centres.

In a cellar of the Observatory there are three batteries. One leads from the directing clock, and propels the two neighbouring regulators, as well as a third clock installed in the keeper's room; this is the

local circuit of the Observatory. The other two batteries are connected, one with the west circuit, the other with the east, having the two regulators above mentioned as checks.

Figs. 491 and 492, show how synchronism is produced in the movements of the pendulums. The pendulum of the standard clock is furnished (Fig. 491) at its upper part with two rods terminating in the form of a T, each carrying on the transverse of the T, the points of three screws, v, v,′ corresponding to three independent levers, a, a', which can turn round a common horizontal axis. When the pendulum, in its oscillatory movement, goes towards the right hand, the points of the screws on this side rise, and touch

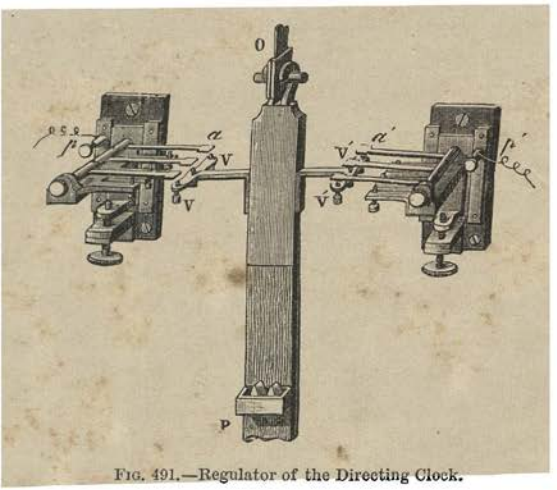

FIG. 491.—Regulator of the Directing Clock.

the extremities of the corresponding levers; when it moves towards the left, contact ceases on the right, but is established with the levers on the left. While the one or the other of these contacts lasts, the current from the local battery passes through the suspension of the pendulum, and the transverse stem of the three levers, which conduct it to the line, on one side to the west circuit, on the other to the east.

The pendulum of the regulator at a time centre carries at its lower end a piece of soft iron, which at each oscillation to the right and left is brought past the poles of an electro-magnet, whose coils form part of the line circuit. The current sent every second

through the directing pendulum excites this electro-magnet at the moment when the pendulum comes opposite to it; the soft iron armature is attracted, and the time of the oscillation, which otherwise would be too short, is prolonged, and synchronism with the motion of the Observatory pendulum clock is established and maintained. Thus perfect concordance between the sixteen regulators of the two circuits with the time at the Observatory is maintained. By consulting the dials of the regulators at these time centres, the public

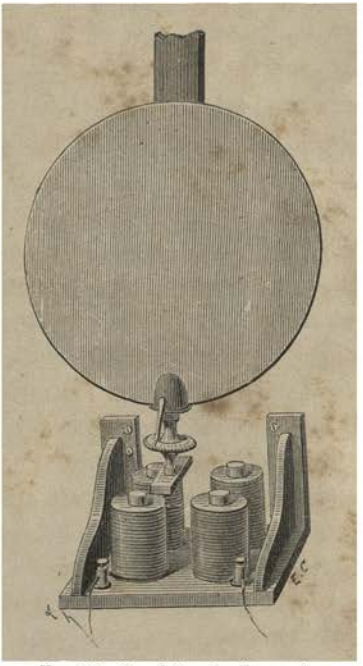

FIG. 492.—Regulator of a time centre.

may regulate their watches to the mean time, with accuracy to a second. The distribution of time is not limited to this. Each time centre, as its name implies, forms a fresh network of distribution, with electrical control between its regulator and all the neighbouring public clocks, but the control consists in nothing more than sending a current every hour which places the hands on the dials of these clocks at the right time. The methods of marking the hour on the different dials are not all alike; the principal clock-makers of Paris who are also inventors of particular methods have been

allowed to make experiments with their systems. An idea of the working of this second part of the service may be gathered from the arrangements in that most important time centre installed at the Préfecture de la Seine. This network extends over the twenty mayoralties of Paris, which are in telegraphic communication with the Préfecture.

"The wires of this network," says Niaudet, "are detached for about two minutes every hour to put the clock of each mayoralty in agreement with the regulator of the town hall. By the side of this regulator twenty relays are placed, into which every hour a current is sent, which has the effect of detaching the line from the telegraph; this communication is made a hundred seconds before the hour. The same regulator, about thirty seconds before the hour, sends a current from a second battery into the lines; this is interrupted exactly at the hour, and consequently has been kept on during thirty seconds. Lastly, at ten seconds after the hour, the relays are brought back, by the suppression of the first current, to their normal position—that is, the lines are joined to the telegraph. On the other hand, sixty seconds before the hour, each of the town clocks detaches the line from the telegraph, and puts it in connection with the electro-magnet of the clock. And five seconds after the hour the reverse is done, and the line is reunited to the telegraph—that is, five seconds before the telegraph is again connected with the time centre.

"As the clocks are thus regulated every hour, their deviations are very slight, and the sectional operations of the line succeed each other as we have said. If, however, a clock gets out of order suddenly, or stops, what happens? The current from the time centre is sent into the telegraph of the mayoralty for the space of thirty seconds; this unusual fact shows immediately to the telegraph clerk that the clock is out of order, and he sees that it is put right."[1]

In short, the system adopted in Paris, for the distribution and electric agreement of time amongst the public clocks of the city unites the double advantage of union and independence in its various parts. The regularity and continuity of the service are made still more reliable by the following arrangements. A clock of great precision, constructed by Fenon, is at the disposition of the Observatory, to control and supplement when need be the underground

[1] *La Nature.*

clock. A commutator also permits the two circuits to be worked together when necessary, by inserting, not only the two complete batteries, but also the contacts of one or other of the clocks at the head-quarters on the line, so that one of them controls all the clocks of the two town circuits, and the other can be cleaned or repaired.

§ 4.—*Chronographs and Chronoscopes.*

The property that electricity possesses of propagating itself almost instantaneously has been employed to measure with great precision very short intervals of time; for example, the time that artillery projectiles take in traversing the distance between the mouth of the gun and the object struck. The pieces of apparatus invented for this purpose are called *chronoscopes* or *chronographs*, the latter being more particularly intended to register time and preserve a written trace of it. Wheatstone was the first inventor of this ingenious application of electricity. The chronoscope that he invented in 1840 was at first arranged as follows.

At the firing-station, A (Fig. 493), a clock C, has a driving weight, and can give on two different dials, E and D, the tenth and the thousandth part of a second. An electro-magnet placed behind the box containing the clock-work is furnished with an armature, which is attracted when a current passes from a battery, and stops the clock. The result of this arrangement is that when the path of the current is interrupted as the projectile leaves the gun, and closed again when it strikes the mark, the clock only goes during its flight, and consequently indicates the exact interval of time occupied. This is done by the battery, P, which is joined on one side to the chronoscope, on another to the target, M, and by a shunt with the cannon, C. The shunt circuit is completed by the wire, *f*, placed across the cannon's mouth, H.

Shortly before making the experiment, the shunt circuit is closed, and the current passes; from that moment the clock is stopped. Then the order to fire is given: the wire is cut by the shot, thus breaking the circuit, and the clock, being released, goes till the moment when, in striking the mark, the projectile puts the two wires

in contact and closes the circuit. The clock is again stopped, and the interval traversed by the hands on the two dials shows, in seconds and fractions of a second the exact time taken for the passage of the cannon-ball.

Wheatstone recognized the inconveniences of this first apparatsu: some magnetism remaining in the armature maintained contact a little while after the circuit was broken; besides, the motion of the hands was not stopped instantaneously as the target was struck: though these differences were very small, yet they were sufficient to render the indications of the chronoscope uncertain, particularly for such small fractions of a second. The inventor succeeded in partly correcting these errors, by employing at the beginning a very feeble current, and by arranging the wires of the circuit so that at the

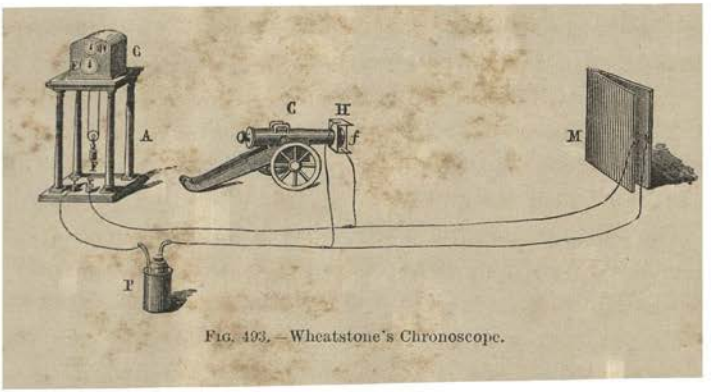

FIG. 493.—Wheatstone's Chronoscope.

instant the target was struck a much more powerful battery could act when the circuit was closed, and give the necessary movement to the armature.

Hipp also modified Wheatstone's chronoscope, rendering the clockwork independent of the indicating hands; so that, whether these were going or not, the clockwork continued. The hands were only in motion during the flight of the projectile.

Pouillet's chronoscopes depend on the "throw" of a galvanometer needle by a known current, according to the time that the current is kept on. Breguet and Constantinoff's chronograph consists of a revolving cylinder, on the surface of which two points supported by electro-magnets successively trace lines at the moment when the projectile breaks two wires, one at departure and another

on arrival, and thus interrupts the circuit: the position of the lines traced on the cylinder indicates the fraction of a turn that it has made during the passage of the projectile. Captain Navez's chronograph was employed with success in ballistic experiments in Belgium and Holland; there is also Martin de Brettes's chronograph, by the aid of which this clever artillery officer has been able to ascertain the initial velocity of a projectile as well as the velocity at any point of its course; also Breguet's chronoscope; lastly, the electric tuning-fork with continuous movement by Mercadier. In this ingenious apparatus, one of the arms of a tuning-fork is attracted by an electro-magnet, whilst the other arm, carrying a platinum wire, is joined to a disk of the same metal, and closes the battery circuit; then the current passes, the electro-magnet acts, the fork vibrates, and its motion continues as long as the current flows. By furnishing the first arm with a registering point, it is possible to mark the vibrations of the fork on a revolving drum covered with lamp black the duration of which can be easily determined, and will permit of a hundredth part of a second being measured. The duration of any phenomenon whatever marked on the drum can be measured with the same degree of accuracy. Wheatstone has applied chronoscopic methods to the study, and confirmation of the laws of falling bodies. In the first volume of the *Monde Physique* there is a description of two pieces of apparatus, electric chronographs, both intended to prove these laws. In the first, the interruptor of a Ruhmkorff coil is used to produce a series of sparks, between a metal cylinder covered with a sheet of paper, and a platinum point which the heavy body carries whilst falling. The traces left on the paper by the sparks lie on a curve the abscissae of which measure the time from the beginning of the fall. The apparatus may be called the *spark chronograph*.

The second registering apparatus, due to Bourbouze, consists of a cylinder, the rotation being uniform or accelerated, according as the weight which moves it has, during its fall, a uniform or accelerated motion. The vibrating plate traces, with its point on the smoked surface of the cylinder, a sinuous curve, the spaces between which can be shown to verify the laws of the falling body.

Chronographs are also used to determine the difference of longitude between two places having electrical communication by means of which to transmit time signals which may be compared with

astronomical observations. They are also employed as adjuncts to the apparatus used to measure the velocity of light. In the second volume of the *Monde Physique* there is a summary of this, and a figure of the chronograph employed by Cornu in his determination.

Finally Marey has shown how chronographic methods may be used to measure the duration of physiological or psychological actions.

CHAPTER X.

ELECTRIC MOTORS.

§ 1.—*Oscillating Electric Motors.*

THE power of electric currents to produce motion, by means of which signals are made and transmitted, is the principle used in telegraphy, and electric clocks: electricity, whether derived from voltaic batteries or produced by magneto-electric induction, is there employed as a mechanical agent or motive force. But the electric current is not always employed in these cases as a primary source of power. Most frequently it only serves to regulate the operation of another force, that of gravity for example; for an apparatus driven by the action of a falling weight may be controlled from a distance by means of a current of electricity which may be used to stop or start the motion periodically.

But electricity may be employed directly as a motive force, that is to say, power may be applied to electricity to force it to flow as a current to a distant point where it enters a sort of electric engine, which it sets into motion, the energy of the electricity in motion being itself here a direct cause of mechanical power. Such electric engines are generally known as *electric motors*. The problem before us is to devise an electric motor which when supplied with electric power from a battery will transform the power so supplied into mechanical power. This problem has received many practical solutions, some applicable only on a small scale, but others adapted for the supply of power for industrial purposes on the large scale.

The earliest electric motors were those of Salvator dal Negro, of Padua, who in 1831 constructed a machine in which a magnet oscillated between the poles of an electromagnet. Professor Henry, of

Princeton, New Jersey, quite independently devised an oscillating electric motor which he described in the same year. About the same time Jedlick, a German, invented a rotatory electro-magnetic machine: other small machines were devised by Ritchie, and by Henry. But it is to Jacobi, of St Petersburg, that we owe the first serious invention of this kind. This motor was constructed in several forms, the earliest in 1834. In 1839, a trial was made of one of his machines, fitted to propel a boat.

"It was applied," says Du Moncel, "to propel a boat carrying twelve persons, and furnished for this purpose with paddle-wheels. They were able to navigate for several hours on the river Neva; but the power developed, though proceeding from a battery of 128 large Grove cells, never exceeded three quarters of a horse-power. Such a small effect from such an energetic source of current completely discouraged the inventor, who always afterwards considered this application of electricity as impracticable for industrial operations."

Following Verdet's classification, we shall divide electro-magnetic engines into two classes, corresponding to two distinct types, *oscillating engines* and *rotatory engines*, and we shall give some examples of each of these types. Then we shall describe the motors of more recent date, and which now are of practical use.

The characteristic principles of these two types of machines are as follows: In the *oscillating motors*, a fixed coil, or electromagnet, when it is traversed by an electric current of suitable strength, attracts, either another coil, or an electromagnet, or a magnetised bar, or even a simple piece of soft iron. When the movable piece approaches so as to come almost into contact with the fixed piece, the movement of the machine actuates a commutator, by means of which the attraction is changed into repulsion, or is replaced by the attraction of another piece placed on the opposite side. The direction of the motion is thus reversed; and these attractions being indefinitely repeated, a to-and-fro motion can be obtained like the motion of the piston of a steam-engine. In older *rotatory motors* the movable and fixed pieces were usually arranged along the radii of two concentric wheels; the passage of the electric current through the fixed coils or electromagnets sets up an attraction which tends to turn the movable wheel towards a position of stable equilibrium; but at the moment it reaches that, the action of the commutator arrests or changes the direction of the electric

currents, allowing the momentum of the moving wheel to carry it forward when again the attractive forces come into play and the rotation continues indefinitely in the same direction.

Bourbouze's Electric Motor (Fig 494) belongs to the first type. The essential arrangements of it are as follows:

Two hollow magnetizing coils or solenoids EE, E′E′ are placed in pairs on either side of an upright frame which supports a beam like that of a steam-engine. These coils correspond to the engine cylinders. Within the coils, and reaching down to half their depth, are soft iron plungers or cores, which are magnetized and consequently

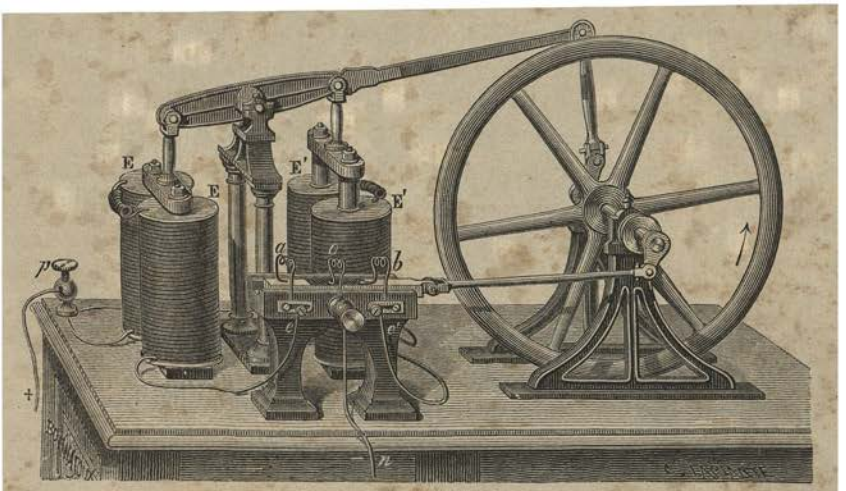

FIG. 494.—Bourbouze's Electric Motor.

drawn into the coils when the current from a battery is passed through the convolutions of the several coils. At the two ends of the beam are short connecting rods which join it to the two soft iron cores. The latter pass quite freely into the hollow spaces within the coils, and are attracted alternately being sucked in when the current magnetizes them, and released when the current is cut off from the surrounding coil. It is easy to see then that, if the current is caused to pass successively and alternately into each pair of coils, the result will be an up and down movement of the pistons and a corresponding motion of the beam. By means of a connecting rod and crank this movement is transformed into a continuous rotation of the axle of the machine and its fly-wheel.

We have yet to explain how the current from the battery is successively turned on and off in each coil. For this purpose, there is applied an apparatus which corresponds to the valve-gear of the steam-engine. An eccentric or a small crank, mounted on the axle of the machine, is arranged to move along a slide an ivory plate *a o b*, covered over part of its length with a metal band.

The wire of the positive pole of the battery communicates at *p* with wires which go off to the two sets of electromagnets; and each of the latter is connected with one of the lower parts of the bed of the slider. Above the middle point, at *o*, is a spring contact piece which is in communication with the negative pole of the battery. Let us suppose that the motor has arrived at the position shown in the figure. The crank has arrived at its highest point, and it is requisite that the electric connexions should be reversed, so that the current may pull down the two plungers which have previously been rising. As represented in the figure this action has already taken place, the slider having been drawn forward so that the metal plate on the ivory slider puts *b* into connexion with *o*. The current then follows the path *p* E′E′*b o n*, for the circuit passing through the coils E′E′ is closed from *p* to *n*. The current cannot pass through the coils EE, because the wire coming from *e* to *a* meets the ivory, and forms at this point no closed circuit. Consequently the cores of the pair of coils EE are released, and can move upwards, whilst those in E′E′ are drawn down. And so, one after the other, the pairs of cores move up and down, and the machine is set into regular movement.

The two moving cores are never withdrawn from their surrounding coils; and their motion up and down is necessarily along a short path, otherwise the power of the current upon them would be feeble. Because of the comparatively short travel of the plungers it is needful to lengthen the beam by a lever of sufficient length to suit the driving crank.

It is easy enough to comprehend this mode of transforming the alternate rectilinear motion, produced by the electro-magnetic forces, into an oscillating movement, which is then mechanically transformed into a continuous rotation.

§ 2.—*Electric Motors with continuous Rotation.*

Let us now consider a type of electro-magnetic machines giving directly a continuous rotatory motion. We will take as an example Froment's motor. Fig. 495 gives a general view of it.

Four electromagnets (or, in Fig. 496, six) are set radially a intervals around the periphery of a circle, and are fixed to the frame of the machine. Upon a central horizontal axle there are fixed two

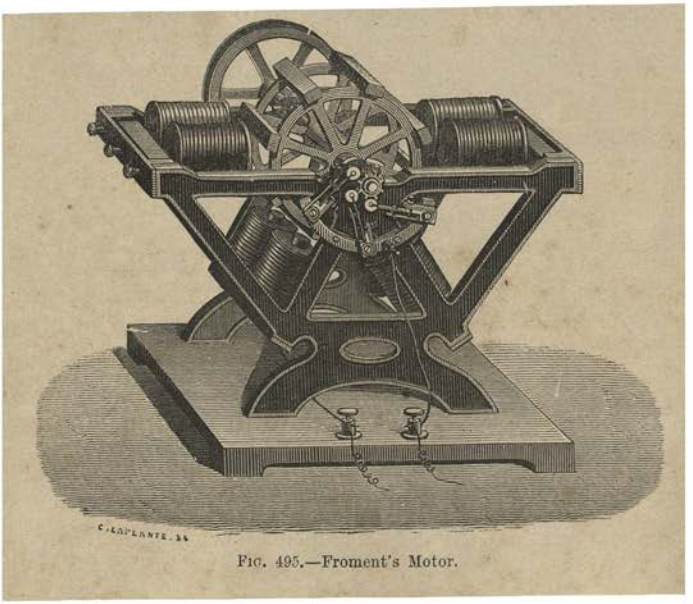

FIG. 495.—Froment's Motor.

wheels which carry eight bars of soft iron, placed parallel to the axis of rotation. As the number of these is different from that of the electromagnets there can never be more than two bars at a time, opposite the poles of the electromagnets, in any position of the whole rotation.

The eight bars being distributed at equal intervals on the circumference of the movable wheel, and the number of electromagnets also equally distributed being, as in Fig. 496, only six, when two opposite bars are exactly in positions facing the two electromagnets E E, the other bars are before or behind the other electromagnets

according to the sense of the rotation. Let us suppose it to be in the direction of the arrows or opposite to that direction in which the hands of a clock go round. In this case, the current of the battery is thrown into the coils E′ E′, and it has left the coils E E. The bars, which follow in the direction of the motion, are attracted, and the rotation will continue in the same sense till a pair of bars are opposite the poles E′ E′. At this instant the current is cut off from the latter coils and sent into E″ E″; and it will now be the turn of the next preceding pair of bars to be attracted, and so on indefinitely. It is clear that during an entire revolution there are as many attractions as correspond to the number of times that the

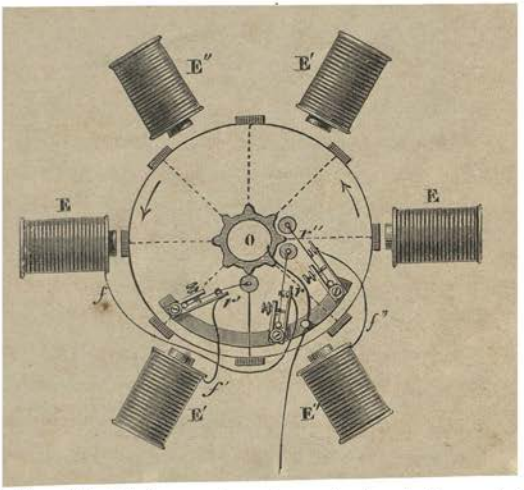

FIG. 496.—Action of the Electromagnets on the moving bars in Froment's Motor.

angle of advance between magnets and bars is contained in the circumference, that is to say twenty-four. For the difference between $\frac{1}{6}$ and $\frac{1}{8}$ is $\frac{1}{24}$.

The successive turning on and turning off of the current in the coils of the machine are accomplished by the help of a commutator or distributor, the arrangements and functions of which can be easily understood from Figs. 496 and 497. This distributor consists of a wheel R (Fig. 497), centred on the axis of rotation, and furnished with eight teeth or cams, the same in number as the bars, and moving with them. This wheel is maintained in constant connexion with the positive pole of the battery. Three stiff

springs r r' r'', (Fig. 496) are fixed to an immovable curved piece which supports them and insulates them from one another. Each of these springs is connected, with the pair of electromagnets respectively opposite, by means of the wires f f' f''. These three springs, which are furnished with contact-tips of platinum, are set close to three more flexible springs, also having contact-tips, and carrying small friction-rollers at their ends. These are set in positions which correspond to the positions of the soft iron bars. The little rollers are moved by the teeth of the distributing wheel as it goes round. When two bars are exactly opposite their corresponding poles, as at E, E, the spring r', which communicates with the next pair of electromagnets E' E', is put into contact, the other two springs being, at this instant, out of contact.

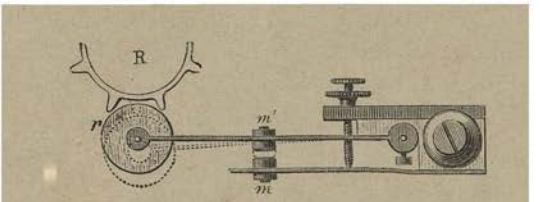

FIG. 497.—Commutator or Distributor of Froment's Motor.

After one twenty-fourth of a turn the roller which presses the contact at r' will quit the tooth, and the contact at r'' will be brought in turn into play; thus throwing the current into the coils E'' E''. In short, the connexions will be shifted at each fraction of a revolution equal to $\frac{1}{24}$, and will pass, by the spring in contact with a tooth into the coils which are at the corresponding angle in advance of the next pair of bars.

The currents, after having traversed any pair of coils, come back to the negative pole of the battery by a common wire. The current only ceases to act on any one pair of electromagnets, when it has passed into the next pair; a very ingenious arrangement intended to prevent the appearance at the contacts, of any spark due to the so-called extra-currents induced by the coils. The oxidation of the contacts which such sparks would produce is thereby greatly obviated, and wear and tear diminished.

§ 3.—*Modern Electromotors.*

Froment's motor which we have just described was invented about 1846. It was shown in several forms at the Electrical Exhibition at Paris in 1881 in the historical collection.

The inventor employed it for several useful purposes named below. Such motors, as well as those based on the principle of the simultaneous attraction and repulsion of two electromagnets, may be passed over as of small interest, because of the very restricted applications of which they are susceptible. They can only be used in a service demanding very little amount of power: turning a small ventilating fan, or light drill such as Froment used in his workshops for engraving on glass, or for driving electrical toys.

That great progress has taken place in the development of electric motors is due to a curious circumstance. It has been known for forty years that every form of electric motor which operated on the principle of mutual mechanical force between a magnet and a conducting wire or coil could also be made to act as a generator of induced currents by the reverse operation of producing the motion mechanically. And when, starting from the researches of Siemens, Wilde, Nollet, Holmes and Gramme, the modern forms of magneto-electric and dynamo-electric machines began to come into commercial use, it was discovered that any one of the modern machines designed as a *generator* of currents constituted a far more efficient electric *motor* than any of the previous forms which had been designed specially as motors. It required no new discovery of the law of reversibility to enable the electrician to understand this; but to convince the world required actual experiment. The researches of Wilde in 1869, on the operation of two magneto-machines coupled together by a connecting wire so that one generated currents which in turn imparted mechanical motion to the other, are too well known to need comment. Gramme himself made many researches on this point. M. H. Fontaine showed at the Vienna Exhibition of 1873 two of Gramme's dynamo-machines similarly coupled; one having the function of generator, transmitting currents along a line to the second which received them and was set thereby into active motion.

The possibility of using these machines in a double function furnishes an admirable illustration of the convertibility of energy, and its transformation from one form to another. On the one hand energy is supplied to the machine in the form of mechanical power, this power being expended in setting an arrangement of copper conductors (called the "armature") to rotate between the poles of a powerful magnet. There is no friction, save at the bearings, and this is reduced by lubrication to a minimum. There is nothing which to an outside observer would suggest that any serious amount of driving power is required. Nevertheless when the generator is at work, furnishing electric currents, its armature cannot be driven rapidly round without great expenditure of power. The mechanical energy so absorbed is being invisibly converted into energy of another species, namely electric energy. In other words the energy which in the first instance consisted in the motion of matter is being converted into an equivalent quantity of energy consisting in the motion of electricity. The generator does not generate electricity; it is generating currents of electricity. Electricity is not generated any more than matter can be. But to set up currents in the pre-existing electricity requires the expenditure of energy just as truly as to set up motion in existing masses of matter. Further, in whatever form energy exists, it may always be considered as the product of two factors. In the case, for example, of the energy spent on raising weights against gravitational force, the energy spent may be stated as so many *foot-pounds;* being the product of a certain pound's weight raised through a certain number of feet. In the case of mechanical power used to keep a body in rotation against resisting forces, the two factors of the product are, the turning-moment or "torque" and the speed of rotation or "angular velocity." In the case of electric power, the two factors are the current, or quantity of electricity flowing per second, and the electromotive-force (or electric potential or pressure) with which it is forced along the circuit. In every magneto-electric or dynamo-electric machine that has its magnet of constant strength, the two factors of the mechanical power applied to drive the armature are respectively proportional to the two factors of the electric power into which it is transmitted. For the electromotive-force is found to be proportional to the speed of driving, and the

quantity of the electric current is proportional to the turning-moment or torque. The same thing is true in the reconversion by the motor of the electric power that comes through the wires into mechanical power. If the current is supplied at a constant potential (or electric pressure), then the speed at which the motor runs will (if its magnet is of constant power) be very nearly constant whatever the load put upon it; and the current that flows through it will be proportional to the turning-force which it is required to exert. The action of well-designed electric motors is therefore beautifully automatic, if the electric pressure of the supply-mains is kept constant. We shall return to this matter by and by when dealing

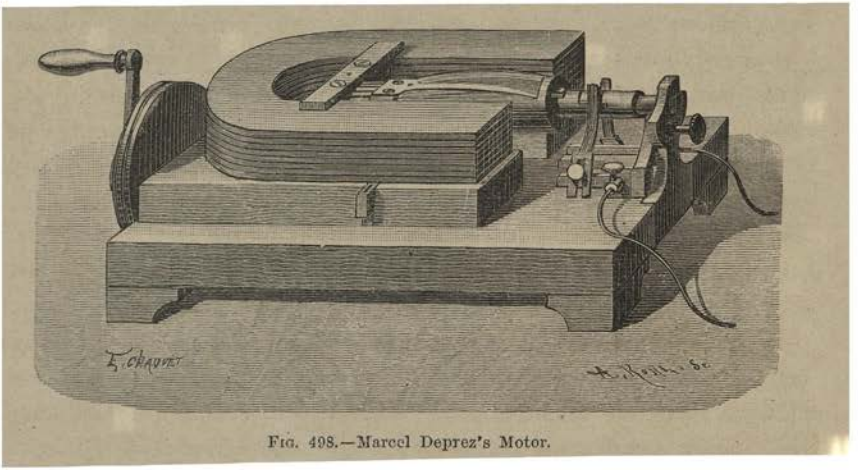

FIG. 498.—Marcel Deprez's Motor.

with the transmission of power electrically to a great distance. Meantime we shall consider some of the smaller electric motors and their useful applications.

In 1878 Marcel Deprez devised a convenient form of small motor, in which a shuttle-wound armature of the simple pattern invented by Siemens was employed. Instead of placing the coil transversely as Siemens had done, in his early magneto-electric machines, Deprez placed it parallel to the arms of the magnet, so as to better utilize the magnetic power of the latter. Fig. 498 shows the arrangement made by the inventor.

Between the arms of a permanent horse-shoe magnet, formed of many superposed plates, may be discerned the Siemens' armature,

turning on its axle, when the battery current passes into it through the brass springs or brushes. From these the current is received by a commutator for reversing the current in the armature at every half revolution. This is necessary, because the armature itself acts as an electromagnet having poles. These poles (which depend on the direction of the current) have to be attracted up to the poles of the fixed magnet, and then, as they pass, repelled from them so as to keep up the rotation. The brushes are fixed upon a frame or rocker which itself is capable of adjustment, being movable round the axle of the armature, so that by shifting it forward or backward more or less, the moment at which reversal of the current occurs is caused to happen earlier or later in the rotation, thus enabling the user to graduate the speed produced by a given current. The direction of rotation can even be changed without touching the wires from the battery: to do so, it is sufficient to rock the brush-holder so as to invert the positions of the points of contact of the brushes and the commutator.

Some of the Deprez motors were also furnished with a speed regulator, which consisted of a small spring, communicating on one side with one of the ends of the wire of the coil; on the other side there is a regulating screw with its point facing towards a piece of platinum soldered to the commutator. This end of the spring is heavier than the other, so that with an increase of speed it tends to fly out by the effect of centrifugal force. Then contact between the point and the commutator ceases, and the circuit is broken; the speed diminishes, but the circuit is closed again so soon as the speed resumes its normal value. This kind of governor acts however spasmodically, and the sparks which occur at the contact render it an unsuitable arrangement for any but the smallest motors unless some device such as carbon contacts is employed to render these sparks innocuous.

Motors of Deprez's kind are capable of rendering great service, when the work needed does not surpass 2 or 3 kilogrammetres (14 to 22 foot-pounds) per second. A little model, the armature of which was only 30 millimetres ($1\frac{1}{4}$ inches) in diameter, and 35 millimetres ($1\frac{1}{2}$ inches) long, and weighed 200 grammes ($6\frac{1}{2}$ ounces), the magnet 1700 grammes ($3\frac{3}{4}$ pounds), and the total weight of which was less than 2 kilogrammes ($4\frac{1}{2}$ pounds), was found to furnish work at the rate of 51 kilogrammetres (370 foot-pounds) a minute with a speed of 204

revolutions a minute when fed from 5 Bunsen cells. Each gramme of zinc consumed in the battery rendered no less than 134 kilogrammetres of work. Another model, the armature of which weighed 400 grammes, and the magnet 1700 grammes, developed 2 to 5 kilogrammetres per second, with a speed of 3000 revolutions a minute. The current was furnished by 8 flat Bunsen cells.

Most of the small electric motors, which have been produced since the construction of the one we have described, are based on the same principle, that of the rotation of a Siemens' armature, sometimes between the arms of a permanent magnet, sometimes with an electromagnet. In Trouvé's motor, an electromagnet of U-shape, is used as a field-magnet instead of a steel horse-shoe. Its exciting coil is traversed by the same current from the battery which passes into the wire of the rotating coil. In these motors the polar faces of the armature core are slightly eccentric, being cut away obliquely, as in some of Wheatstone's earlier motors, with the view of gaining continuity of action so as to carry the motion on past the points of commutation, which are, in motors furnished with these simple forms of armature, the dead-points of the machines. In order to do away with the inconvenience of the dead-point, which occurs at the position when the commutation in the direction of the current is brought about at every half turn of the coil, Deprez suggested the construction of a double armature: the core being divided into two equal parts, in the direction of its length, each half being wound with a separate coil and provided with a separate commutator, and the two set at 90 degrees to one another, so as to come into action alternately.

The limbs of the field-magnet of Trouvé's motor support a copper frame to which are fixed the brushes, the bearings between which the armature is centred, and other accessories. A toothed wheel is mounted vertically by a bridge over the magnet, thus enabling the motor to be connected either by wheelwork or by chain-gearing to any object which it is desired to drive. The battery which works it is a special form of bichromate battery, and according to the inventor the consumption of 1 gramme of zinc suffices to yield 95 kilogrammetres of work. To obtain greater power, Trouvé doubles or trebles the number of armatures, and of batteries that work them. We shall speak of these useful forms

again, in reference to their application to sewing-machines, to boats, and to balloons.

Sundry other small motors, including those of Griscom (Fig. 499) Bürgin, and Borel, chiefly useful for driving sewing-machines, were shown at the Exhibition of 1881. In Griscom's motor, the armature rotates between the two poles of a tubular electromagnet, which surrounds and encloses it. A battery of 6 bichromate cells suffices, when it is used to drive a sewing-machine.

We have said above that these little electro-motors with two-part commutators that merely reverse the currents, whether constructed

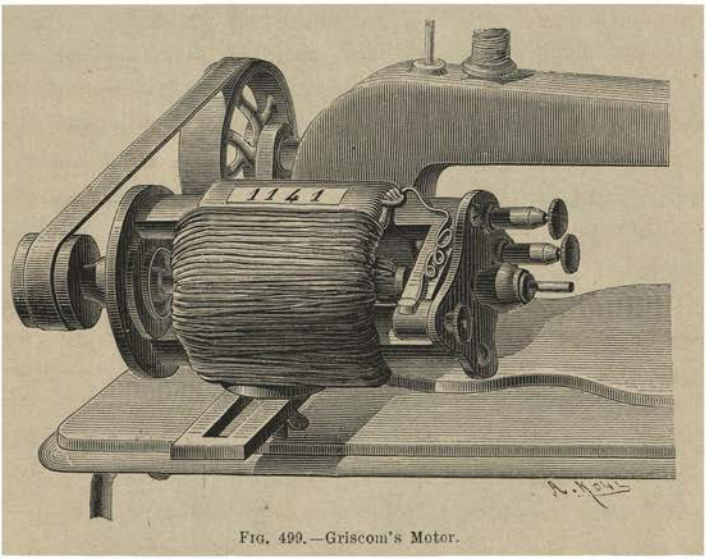

FIG. 499.—Griscom's Motor.

with electromagnets or steel magnets, are suitable only when the work required does not exceed a few foot-pounds per second. For greater power, we must employ continuous-current machines such as Gramme's and other modern dynamos. Only such are able, as we shall see later on, to furnish a practical solution to the problem of the transmission of power to a distance. Motors of Marcel Deprez's type may be used in many cases where the power wanted is not great. We have already mentioned sewing-machines; within the same category come opticians' dividing-engines, watchmakers' lathes, and all instruments requiring regularity and precision with slight

power. Deprez's motors are used in Baudot's multiple printing telegraphic apparatus.

At the International Exhibition of Electricity in 1881, the curiosity of the public was excited by two applications of Trouvé's motor, on which we must say a few words. There was on the artificial lake in the centre of the palace, a boat propelled by electricity. Some months previously, trial-trips made on the river Seine

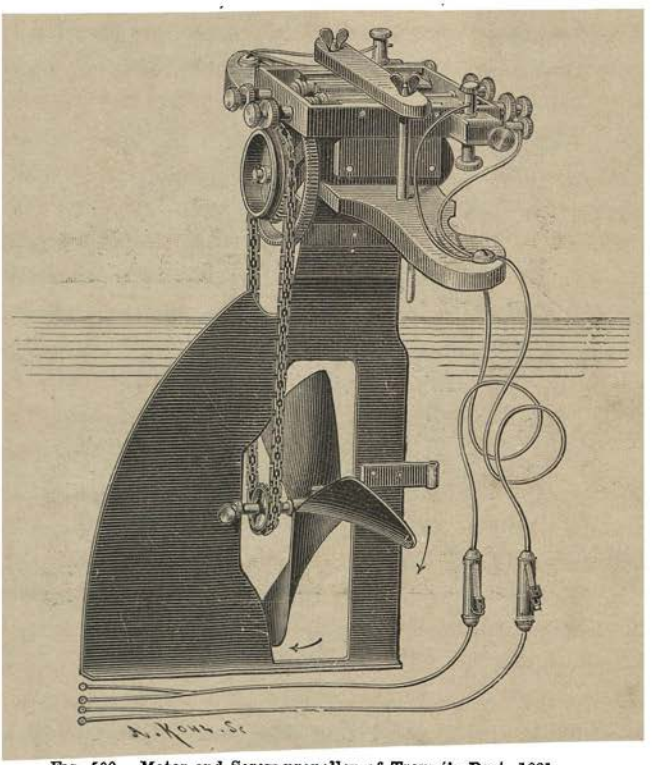

FIG. 500.—Motor and Screw-propeller of Trouvé's Boat, 1881.

and on the lake in the Bois de Boulogne had given satisfactory results: in the first, the boat carrying three persons easily ran against the stream with a speed of a metre a second, in descending it acquired a speed two and a half times as great. The motor, placed on the upper part of the rudder, was of Trouvé's double pattern with two armatures, worked by two bichromate batteries placed in the middle of the boat. Fig. 500 shows how the move-

ment was communicated, by the aid of chain-gearing to a screw-propeller mounted in the lower part of the rudder. The communication of the batteries with the motive parts is made by means of the same appliances which serve also to work the rudder; these are formed of flexible metal cords, well over-spun with silk and cotton, and then put into an india-rubber tube which shields them from accidents or damp. The person who steers the boat holds in each hand one of these cords, as in the ordinary steering of pleasure boats.

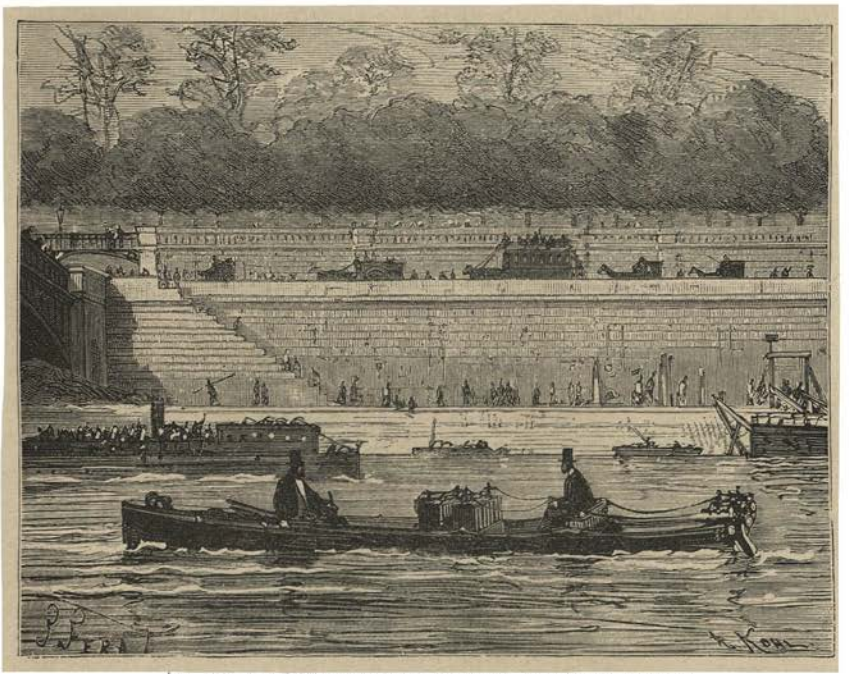

FIG. 501.—Trial-trip of Trouvé's Electric Boat on the River Seine.

But half way along each cord, as shown in Fig. 500, there is placed a handle provided with a push contact so that, by a simple movement of the thumb acting on the knob of the push, the steerer can turn on the electric current and start the boat, or stop it, at once. Fig. 502 shows, in plan, the general arrangement of the double motor and the two batteries on Trouvé's boat.

Is this ingenious application of electric motors to navigation susceptible of extension to vessels of a considerable tonnage? The

answer to this question appears no longer doubtful. The primary battery is not only a costly source of electricity on account of the cost of the zinc and acids consumed, it is also inconvenient, and the duration of its action is very limited. So long as there was no more powerful means of carrying about a store of electric energy, it was hopeless to expect any great extension of electric navigation, and such boats as Trouvé's which are mere substitutes for light rowing boats would have remained a luxury and a curiosity. Rowing is a sort of sport which derives all its interest from the muscular vigour and dexterity developed by those who pursue it: it is besides a useful gymnastic exercise for young people. The substitution of a mechanical motor for the oar, however powerful it might be, would prove simply the death of boating.

Since the introduction in 1881 of practical forms of electric accumulators, the problem of electric navigation has assumed a new

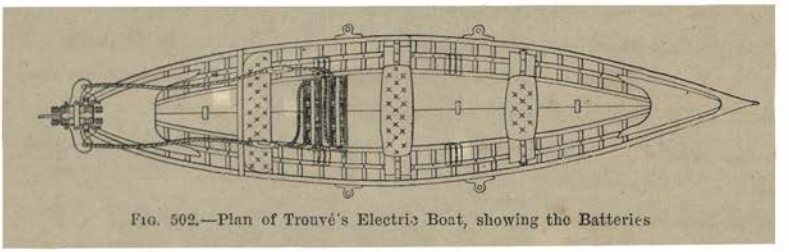

FIG. 502.—Plan of Trouvé's Electric Boat, showing the Batteries

and more important phase. In 1882 the Electric Power Storage Company, of Millwall, constructed an electric launch propelled by two of Siemens' dynamos which actuated a screw-propeller, and were in turn driven by the electric current derived from forty-five accumulators of the Faure-Sellon-Volckmar type, capable of giving out four horse-power for six hours, or three horse-power for nine hours. This boat, an iron one of nearly thirty feet length and five feet beam, received the name of *The Electricity*. The average speed attained was nine miles per hour with the current, and eight against. These results have however been surpassed by several electric boats which have since been constructed. In 1885 the *Volta* succeeded in crossing the Channel and returned in safety without having her accumulators recharged. The latest boats propelled by electricity are the *Countess*, ninety feet in length, provided with an Eliesen motor, and accumulators by the same constructor;

the *Nautilus*, twenty-eight feet in length, actuated by a Krebs motor and one hundred and thirty-two of Demazures' accumulators; and the *Viscountess Bury*, 65 feet in length, provided with 160 accumulators of a special type made by the Electric Power Storage Company, and with a propeller worked by an Immisch motor running at 700 revolutions per minute and giving eight to ten effective horse power. There is now a fleet of ten electric launches on the Thames and eight public charging stations, three fixed and five floating; the latter can be placed where most needed. Any launch requiring its batteries charged is placed alongside one of these stations at night, and in the morning it is ready to proceed on its way with a full store of energy. At the Edinburgh Electrical Exhibition of 1890, four electric launches, each forty feet long and capable of carrying forty people, were employed to carry visitors to and from the Exhibition along the canal, thus plying for hire after the manner of ordinary river steamboats. They were fitted with E.P.S. cells and an Immisch motor.

The future is full of promise for electric aerial navigation. The great advantage of an electric motor over a steam-engine is the absence of fire and smoke, an advantage of enormous importance when it is remembered that the balloon is filled with inflammable gas, sometimes actually with hydrogen. The whole question in such a case turns upon the possibility of devising an accumulator and motor of greatly reduced weight in proportion to the power stored. Another advantage in the electric motor is that of constancy of weight, as it does not emit into the air any products of combustion which, by continually making the balloon lighter, tend to make it mount in the atmosphere. Monsieur G. Tissandier, the well-known aeronaut, designed a steerable balloon moved by electricity, a model of which was shown at the Exhibition of 1881. Tissandier has made a series of very encouraging experiments which prove as far as they go that we may hope for success on a large scale. He used to propel his balloon by a Trouvé's motor worked by a Planté's secondary cell.

This balloon, the form of which was similar in type to Giffard's elongated balloon, or to that of Dupuy de Lôme, measured eleven feet in its longest dimension and nearly six feet in diameter at the middle. Filled with pure hydrogen, its lifting power was nearly five pounds. The weight of the motor was under eight ounces

that of the Planté's cell also eight ounces. The motion of the armature was communicated by gearing to the shaft of the propeller, which consisted of a screw with two very light blades measuring 16 inches in diameter. In calm air the armature made six and a half turns per second, and the speed of propulsion was over three feet per second; the movement lasted forty minutes. "With two secondary cells mounted in series," says Tissandier, "each weighing one pound, I can fit to the motor a propeller two feet in diameter which gives the balloon a speed of about six and a half feet a second for a space of ten minutes. With three cells the speed attains ten feet per second."

Tissandier is of opinion that the following are the conditions under which the results obtained in a small way would probably be bettered if the experiments were made on a larger scale. "Under the present conditions," he says, "a dynamo-electric motor can give 6 horse power with a weight less than 660 pounds, with 2,000 pounds weight of secondary cells. It would be easy to raise, along with oneself, this material of a total weight of $1\frac{1}{4}$ tons by means of an elongated balloon, having a capacity of 3,000 cubic metres, filled with hydrogen, like those that have been guided through the air by Giffard in 1852, and by Dupuy de Lôme in 1872. The balloon should be 130 feet long, and 45 feet in diameter in the middle; its total ascensional force should be $3\frac{1}{2}$ tons. It would itself with net and car weigh about one ton: there would then remain more than one ton to spare for passengers and ballast. In calm weather, this balloon, worked by a screw-propeller sixteen to twenty feet in diameter, would have a speed of thirteen miles an hour, and with much movement in the air it could be steered out of the line of the wind; certainly it would not work for more than a limited time, but it would allow of the carrying out of quite decisive experiments."

§ 4.—*Various Applications of Electric Motors.*

The electric motors that we have described do not come into competition with steam-engines, except in such cases as those where the natural power of a waterfall or river can be used to generate the

electric current to supply the motor: or in the case of small motors supplied with currents from a central station. The reason is given by reference to the principles of the conservation of energy.

The power of the electric motors is only as it were a secondary power derived from the electric currents supplied to them from some artificial source. The three main practical ways of generating electric currents are (1) by dynamo-electric machines driven by mechanical power, (2) by voltaic batteries wherein zinc and acids are consumed, (3) by thermo-electric piles and batteries. In point of cheapness neither of the two last methods can compete with the dynamo-machine. But the dynamo-machine itself requires a source of power to drive it. It is a mere matter therefore of common sense that it will be cheaper to use a steam-engine to do a piece of work direct, than to use that steam-engine to drive a dynamo to generate electric currents in order to drive an electric motor to do the work. The great exception to this argument comes in, as we shall see in the next chapter, in the case where it is required to transmit power to a distance; or to distribute power from a large central engine to a number of places where small power is required.

But, though small electric motors worked by batteries cannot compete with the steam-engine or the gas-engine, or with water power, though their employment in great workshops has long seemed impracticable, there are services of another order that they can render, whenever it is necessary to obtain small power, but perfect regularity, great speed, or to utilize power at a distance. In such cases they possess a superiority which is increased by the facility of arrangement, by the easy way in which they are controlled, the absence of all danger, and the small space that they need. We will give some examples of the varied applications of which they have long been susceptible. Froment the inventor of the machine with direct rotation which we have described above, made use of similar machines for the delicate operations of scientific mechanism to which he was devoted. In his factory he used them to drive turning-lathes and dividing-machines, those exquisite instruments that trace on a glass surface divisions so close that there may be 2,000 or 3,000 of them in the breadth of an inch. The infinite precision and delicacy of this machine made it a mechanical marvel, as may be judged by the following passage in Dumas' report of 1872:—

"Meeting us in London, on the occasion of the Exhibition, Froment in the midst of a conference took out his watch, and said: 'It wants ten seconds to mid-day. According to the time-piece in my room at Paris, my divider begins work. The diamond traces five lines in the air, to put itself in working order, and to warm up the oil of its joints and supports. It traces five useless lines on a glass plate, to make sure that the stylus bites. It moves on to the place where it ought to begin work; it traces its lines definitely, short ones for the thousandths of millimetres, taking a longer stroke at every fifth, and at every tenth stroke a longer still. It has traced five hundred. It has finished its work, and rests in its place—the point raised ready to recommence. But, in its turn, it marks on the timepiece thirty seconds after twelve, so that on his return to Paris the master may see that his electric servant has scrupulously obeyed him.'"

Since that date immense progress has been made. Electric motors are now constructed which when supplied with proper currents are capable of developing from 200 to 300 actual horse-power. The electric motor is therefore now in a position not only to perform light and delicate tasks, such as those for which Froment used it, but also to undertake the heavy burdens for which hitherto the steam-engine has been the only appropriate servant of man.

CHAPTER XI.

ELECTRIC TRANSMISSION OF POWER.

§ 1.—*Transmission of Power.*

IN the last chapter we have seen that the principle of reversibility, applied to dynamo-electric machines, gave rise to important progress in the construction of electro-motors.

So long as the source of the current was a primary battery, in which the electrical energy was derived from the energy of chemical separation as in the case of zinc burning in an oxidising medium—a costly and cumbrous operation—so long was it necessary to restrict the magnitude of the operations. But the question changes when it is possible to employ as generating machines, large continuous current dynamos, like Gramme's, in which the source of the electrical power is the mechanical power of any prime-mover. If, in short, you drive a Gramme machine by the aid of steam or by a fall of water, then join it electrically with a second machine identical with the first, the latter will be set in motion and will transform into mechanical work the electric energy which was itself originally produced mechanically. It must always be remembered that in this transformation part of the energy given to the generating machine is dissipated and lost in the form of frictional heat in the machines, and in the circuit. The utility of transforming electrical energy into mechanical work by this mode of transmission would vanish, or even be distinctly wasteful, if it did not solve a problem only partially solved by other methods, namely, that of the transmission of power to a distance. As a matter of fact, in great workshops and factories the transmission of power, whether from water-wheels or steam-engines is necessarily restricted to short distances, as it can only be accomplished by means of shafting and

belting, or by télédynamic cables. In the case of gas or waterfalls the working substance may be transmitted under pressure in pipes, or employed in a suitable motor to compress air which circulates in tubes: such methods have been used in tunnelling through the Alps at the Col de Fréjus or Saint-Gothard. But in all these cases the distance is necessarily limited, and the arrangements for the transmission of the power also necessitate the installation of costly works. Electrical energy on the contrary passes with the velocity of light from the generating machine to the receiver or motive machine, without other material connection than a metal conducting wire suitably insulated.

Successful experiments on this transmission on a large scale have already brought this new application of electricity within the scope of industrial applications. Before describing any of these we must consider very carefuly one important point, namely the influence which distance has on the efficiency of our combinations, and how the diameters of the conducting wires ought to increase with the amount of power to be transmitted. Marcel Deprez, who has very carefully studied the question of the electric transmission of power to a distance, has shown that, neglecting the mechanical friction of the two machines, the efficiency in question is equal to the ratio of the electromotive force developed by the rotation of the second machine or motor to the electromotive force of the first machine or generator, and that, this ratio being independent of the resistance of the circuit, the efficiency is itself independent of the distance provided a suitable conductor and suitable machines be employed. Theoretically a wire of very small diameter can transmit an unlimited quantity of energy, but on the condition that the total electromotive force developed shall rise as the cross-sectional area of the wire diminishes. It is this last condition that imposes a limit to the fineness of the wire, because of the difficulties of insulation when high potentials are employed. These considerations have been pointed out independently by Sir William Thomson, and Deprez in referring to them says: "On turning to well known experiments on the subject at Sermaize, and Noisiel, &c., it has often been asserted that distance was a very prejudicial element, and that the greater it became, the thicker must the conductors be. Others, magnifying still more this unfavourable influence, have said that, to transmit to a distance the power of the falls of Niagara,

more copper would be necessary than is hidden in the mines of Lake Superior. I was not wrong then in affirming a truth thus unacknowledged." "But, a short time since, this truth became manifest, and by a reaction common enough in the history of science, some have not feared to affirm in conferences, and in articles in scientific journals, on the authority of English and American philosophers, that to distribute over the whole world the power of the falls above mentioned, a small cable of $\frac{1}{2}$ inch (about thirteen millimetres) diameter would suffice. When it is remembered that the quantity of power spoken of represents at least two millions of horse-power, and probably much more, it must be clear that the philosophers in question have not a very good idea of what this number represents, or that they have made errors in the calculation which should have been revealed by the absurdity of the result." Deprez shows that taking only an efficiency of 50 per cent., and a distance of seventy-five kilometres (about forty-seven miles), the generator, if its internal resistance be taken into account, must develope an electromotive force of a million and a half volts, a potential of which lightning alone can give us an adequate idea.

Applying the theoretical principles mentioned above to the calculation of what would be given by two identical Gramme machines (of type C. often used for electric lighting) united by a pure copper wire, four millimetres in diameter, Deprez finds that the efficiency would be 65 per cent. "It is possible," he says, with two machines of type C, to transmit ten horse-power to fifty kilometres distance, by means of an ordinary telegraph wire, the initial power employed being about sixteen horse-power.

It is easy to see the immense development such applications might have in the future, if all the difficulties which present themselves in practice can be overcome. Not only power generated in any place from such sources as are already available could be transmitted to distant places, and distributed; but many natural sources of energy at present useless because they are too far from the centres of population or are inaccessible, would spread in all directions thousands and millions of horse-power, which now is lost. We shall now briefly describe some of the experiments which have already been performed, and which prove that the electric transmission of power does not rest in a state of theoretic prevision. We have pointed out

that Fontaine made the first application of the principle of reversibility in 1873, at the Universal Exhibition at Vienna. Then followed the application of electricity to agricultural operations by Felix at Sermaize, by Menier at Noisiel; the installation of electric railroads, and tramways at Berlin by Siemens; the display of these different applications in the Electrical Exhibition at Paris in 1881; and many numerous and important developments since carried out. Some of these we shall now rapidly review.

§ 2.—*Agriculture by Electricity.*

In May 1879 an interesting experiment was made by Felix on a sugar farm at Sermaize (Marne). The object was to plough by electricity, the necessary power being transmitted by an electric current from a workshop to the field to be experimented upon. The following arrangement was adopted.

The plough to be moved was a double reversing one, bearing three shares on each side like those which are in use in steam-ploughing and which make six furrows at a time. Two reels were placed at the two extremities of the furrows to be traced, and the steel cable dragging the plough was unrolled from one of these and rolled up on the other. Each of the four-wheeled trolleys that carried the reels, carried also two Gramme machines driven as motors by the electric current generated by two other Gramme machines, worked by a steam-engine in the sugar-house and connected to each trolley, by two wires, from 30 to 40 square millimetres in cross-sectional area. The movement of the motors was communicated to each reel in the following way: On each trolley was a central axle bearing at one end a pulley, driven by friction pulleys on the motor; at the other end were two pinions, one of which turned the reel, whilst the other drove the wheels of the trolley. When the furrows were finished in one direction the current was passed by the aid of a commutator into the Gramme machines of the second trolley, which in its turn moved the plough, in the other direction. When twelve furrows were thus turned, the trolleys themselves were moved on by the action of the machines on the second pinion of the central axle. Barral gives the following details of the results obtained in this experiment: "Under ordinary circumstances the generating

machines of the workshop absorb thirty horse-power; of this fifteen horse-power can be used on the plough at a distance of 2 kilometres. The efficiency is therefore 50 per cent., but it diminishes with the distance, and at 5 or 6 kilometres it is only 40 per cent. Great progress is therefore still possible in this respect, and the employment of more perfect insulators is a problem to be solved. We need not hesitate however to employ more powerful apparatus, when the importance of the work permits; and we might thus work at a distance of many kilometres from the centre of the farm. Of course instead of

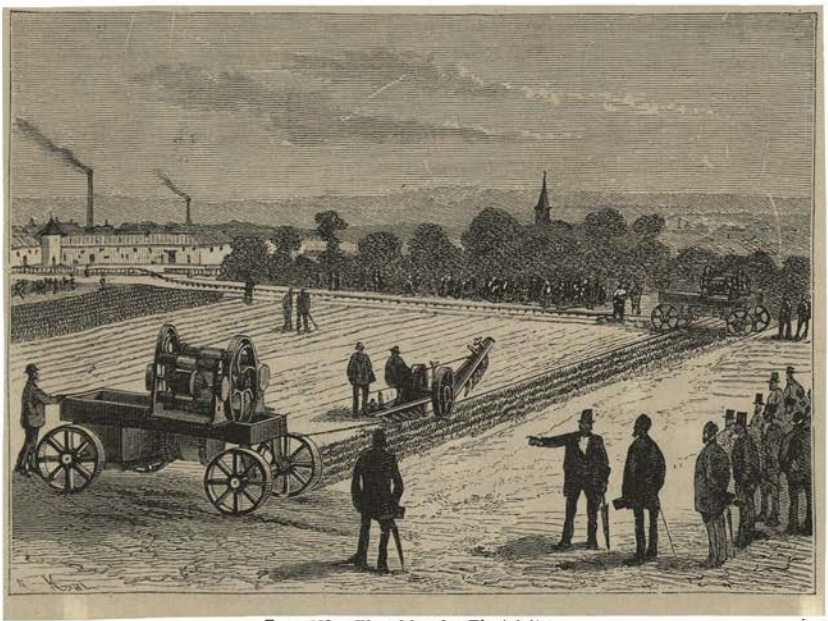

FIG. 503.—Ploughing by Electricity.

the plough, harrows, rollers, cutters, seed-droppers, reapers, in short all the apparatus which are used in fields could be connected with the cable. The price of the ploughing apparatus including the two Gramme machines of the workshop, the two rollers with their electric motors, the traction cables, and the copper conductors for 1 or 2 kilometres is about £2000. These machines however can be used for many other purposes, especially for producing the electric light."

It is asserted that the Sermaize plough ploughs between three-quarters of an acre and one acre per hour, and therefore seven and a

half to ten acres in a day of ten hours. The same system has been applied by Felix and Chretien to discharge the boats bringing the beetroot to the sugar-house, and to fill the waggons which carry it to the workshop. Arbey has used it to drive two saws, one rotatory for cutting planks from the trunks of trees, the other vertical, for more delicate work. Piat has made use of it in quarries, for pounding stone with a very ingenious stamper. Barral, to whom we owe part of these details, thus describes the application of electricity to work centrifugal pumps: "On the axle of the pump a pulley is fixed, which is driven by friction rollers from a Gramme machine. A lever easily worked by the hand increases or diminishes the friction and thus accelerates or retards the speed of the pump. These great centrifugal pumps are now employed for various purposes: on the borders of the sea, where the ground is below the level of high water, they are employed for draining; in the south they are used for irrigation, and for submerging the vines. In the environs of Béziers, for example, Dumont has applied the electric transmission of power to the latter purpose. The advantage is manifest when it is remembered that the necessity of putting up a steam-engine at every pump is abolished, and that since these electric machines take their force from a central fixed steam-engine, the latter can be a modern condensing engine whose employment will very much diminish the consumption of fuel." Electric ploughing has also been used by Menier at his farm in Noisiel. There, the motive power which drove the Gramme dynamos was a waterfall, which was naturally more advantageous in an economic point of view than steam.

In short, it is easy to see that the electric transmission of power which we have described, and of which we have quoted some applications, is particularly adapted to cases where power is supplied by nature, or generated from steam and in workshops where power has to be distributed; it would be more advantageous still in shops where, the work of the machines being intermittent, the whole of them are not in use at the same time.

§ 3.—*Electric Railroads and Tramways.*

Among the applications of the transmission of power by electricity one of the most interesting and perhaps also the most important, is that in which one or more cars on the rails of a railroad or a tramway are driven electrically. Siemens of Berlin first made trials in this direction. During the whole time of the Berlin Exhibition in 1879 the first electric railway worked in a very satisfactory manner. The train was made up of a small electric locomotive with four wheels moving three carriages each with room for six persons, and with four wheels. The motor was a continuous current machine of the Siemens type, placed on a higher level than the wheels. The currents were conducted to the machine by means of a pair of brushes, like Gramme's collectors, which rested continuously on a central rail, consisting of an iron bar placed in the middle of the road, and insulated by wooden blocks. This rail was in circuit with one pole of the fixed generating dynamo, of the same type as the motor, and the other pole of the dynamo was connected metallically with the two ordinary rails. After passing through the motor, the current returned by the wheels and the rails. Moreover, to increase the conductivity, all the wheels of the cars were joined to those of the locomotive by copper wires.

The driver was seated above, and had on his left hand a switch, which enabled him to set the train going by completing the circuit, or to stop the train by interrupting it. In the latter case with his right hand he worked a brake, which skidded the front wheels and helped to stop the train.

The mean speed, in the first trial, reached 2 to 3·5 metres per second, and the power utilized amounted to between two and three and a half horse-power, not including the moving of the machine.

Two years after, Siemens and Halske inaugurated with some modifications a small electric railway, of a total length of one and a half miles, between the central Institute of cadets, and Lichterfelde, a station on the railroad from Anhalt to Berlin. In this installation the central rail is abolished and the rails of the road serve as conductors, and it is therefore necessary to insulate them from all contact with the ground, except with the wooden sleepers on which

they rest. The fixed generating machine, installed in a building of the Lichterfelde station, is worked by a rotatory steam-engine. Copper cables, starting from the poles of the dynamo, pass under the ground and convey the current to the rails, whence it passes to the locomotive. This latter is like an ordinary tramcar and carries passengers to the number of twenty-six, without the aid of horses or a separate locomotive.

Between the two pairs of wheels of the vehicle is installed the Siemens' motor which drives these wheels; a pulley on the axle of the armature drives two rollers which turn each in a groove in the circumference of each of the wheels on the same side of the carriage, so that the two axles are put in motion at the same time. The current passes from the generating dynamo to the motor of the tramcar by the rails which serve as conductors. From these the direct contact of the metal wheels makes it pass to the circumference of these wheels, and thence by metal bands to a cylindrical commutator on which the collecting brushes in connexion with the motor always rest. By the aid of a switch which the driver can work at each end of the vehicle, he can set the car going, or stop it.

The total weight of the locomotive carriage of this electric tramway, with its full number of travellers is nearly five tons: it ought to go at the average speed of twelve miles an hour; but on the horizontal line a speed of from nineteen to twenty-four miles per hour can be reached; the motor, which weighs half a ton, develops 5·5 horse power.

In this system of the electric tramway of Lichterfelde, Siemens and Halske have been able, as we have seen, to employ the rails of the road as conductors, both as line and return. These rails, in Vignole's system, are separated from the ground, from which they are also insulated by the wooden sleepers. But this mode of communication between the fixed generating dynamo and the motor of the vehicle cannot be employed in tramways which have to pass over public roads, along which ordinary carriages, horsemen, and pedestrians must pass continually. Consequently, at the first, Siemens asked for authority to establish an overhead line, which is the most rational solution of the difficulties for this kind of tramway: the insulation of the conductors would have been thus as complete as possible, and ordinary traffic would not have been

interfered with by a conductor at the height of the first story. But the permission requested having been refused, the inventors were obliged to make their trial on a line established on a level with the ground, separated from the ordinary traffic like other rail roads. Having obtained the concession for a line of tramways between Charlottenburg and Spandau, which had to run on a level with the ground, they invented a special arrangement to establish the electric circuit of the machines. This arrangement consists of a

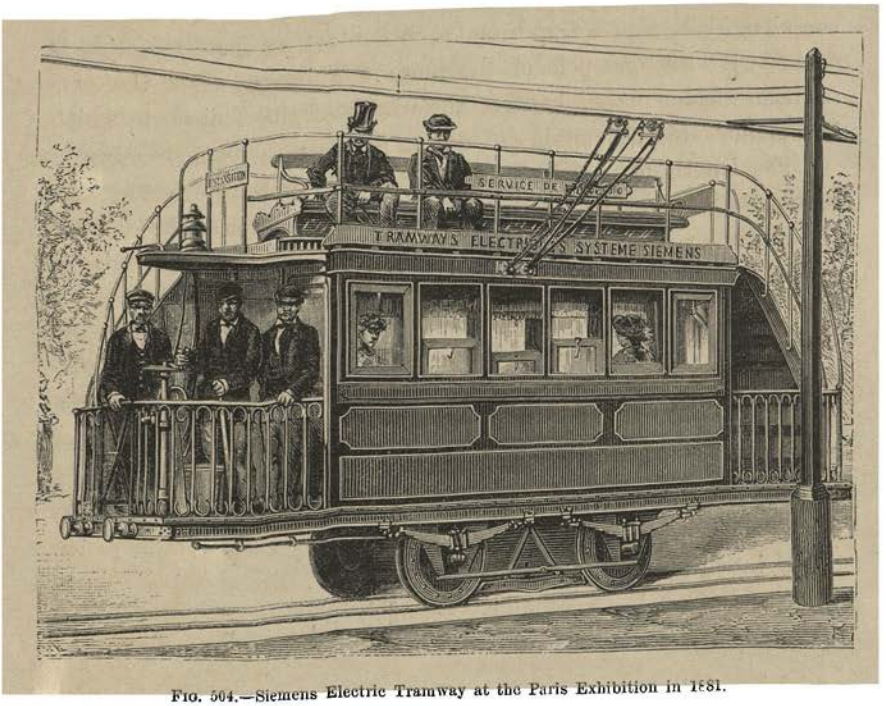

FIG. 504.—Siemens Electric Tramway at the Paris Exhibition in 1881.

movable contact, in a little carriage rolling on a conductor in the air, which is itself supported by posts, like those for telegraphic wires. This aerial conductor serves for the transmission of the current to the motor, and the rails serve as a return path.

Such is the arrangement that was adopted for the electric tramway that visitors to the Paris Exhibition of Electricity in 1881 were able to see at work, between the Place de la Concorde and the east entrance of the Palais de l'Industrie; only the rails there

not being available for conductors for the return current, because of the impossibility of insulating them from the ground, it was necessary to have two aerial conductors, and two movable contacts to complete the electric circuit. These conductors were tubes of brass fixed to bars of wood supported between the posts by cables, like those of suspension bridges. Inside these tubes ran a kind of shuttle of brass, whence descended two vertical stems, on which slid a cross-piece bearing a roller, resting against the tubes at the upper part of its circumference. A longitudinal slit allowed this system of contacts to run along the conductors. From each contact an insulated wire is connected with one pole of the motor. This was, as in the cars at Lichterfelde, placed between the wheels of the vehicle, to which it communicated its motion of rotation by means of chain gearing.

The length of the line was about 500 yards, which the locomotive passed over on an average in two minutes, or at the speed of ten miles an hour, but it could have gone four times as quickly. Completely laden with its fifty passengers, the car weighed about nine tons. The road had two sharp curves, one of sixty yards, the other of thirty-two yards radius, and on a certain part of the way a rise of one in fifty. The power developed by the machine was on an average 3·5 horse-power on the flat straight road; on the curves it was 7·5, and on the rise 8·5 horse-power; hence the necessity of a regulator. For this purpose, the driver had a rhéostat under his control with which he introduced when necessary suitable resistances into the circuit. He also used these resistances just before stopping the car, by breaking the circuit.[1]

[1] "As regards the regulation of speed the following observations were made by Frœlich and Siemens in the case of two machines joined together, working one as a generator the other as a motor. When the electric locomotive is left to itself on flat ground, where resistance to the traction is small, its speed increases till the moment when there is a constant difference between the electro-motive force of the generating machine and the opposite electro-motive force of the motor; the speed of the carriage is then uniform. When there is an incline to ascend, and the power required is greater, the speed diminishes till the counter electro-motive force is in a certain measure weakened, and there is a new difference established between it and the electro-motive force of the generating machine. And then the speed again becomes uniform. If the carriage descends an incline, and a new force of propulsion is thus introduced in the same direction as that due to the current, the counter electro-motive force increases in intensity, and beyond a

The experiments we have referred to show that the traction of tramcars by electricity has entered the domain of practice. We shall say nothing about the economic side of the question. For large cities, particularly where there is a possibility of established aerial roads, there is no doubt but that this mode of propulsion would have many advantages. The substitution of a fixed machine for the steam-engine, abolishing fire and combustion on the line, and consequently steam, smoke, and smuts, would also abolish with one stroke all the inconveniences that have prevented the use of ordinary locomotives in large cities. These advantages would be more palpable still with electric traction in underground railways. In this particular case, the power of the generator could also produce the light indispensable for long tunnels.

Messrs. Siemens have proposed the application of their system for the transport of dispatches and postal parcels. In the month of August, 1879, a French electrician, Bontemps, proposed the same thing, and experiments were made of a small electric postal railway in the court of the Administrations of Telegraphs, under the direction of Marcel Deprez; the electric locomotive which he had constructed for this purpose was to circulate inside the sewers of Paris. This project of an electric post, which has been given up, certainly deserves to be thought of again. Deprez's electric locomotive as well as the little postal train of Siemens, which consisted of a Siemens motor

certain speed becomes greater than the electro-motive force of the generator, and the motor of the car acts as a dynamo.

"In the transmission of power to a distance by the help of two dynamo-electric machines, the resistance of the interposed conductors interferes considerably, and there is only good work when this resistance does not exceed that of the machines. In electric railways working on uniform rails, this resistance increases continually as the locomotive gets further from the generator. It is then necessary to seek for means of preventing this resistance from exceeding a certain limit.

"With lines of moderate length, like that of Lichterfelde, the section of the rails is large enough for their resistance never to be too much. If however there was a longer distance to pass over, the conductivity could very easily be increased either by adding lateral conducting bands or feeders, or as was proposed for the aerial railways, by mounting them on longitudinal iron frames, and making these frames also serve as conductors. But the question can be better solved otherwise without diminishing the resistance of the conductors, by increasing that of the wire of the machines. Then, it would only be necessary to adapt the machines to the distance the carriage was required to travel."

mounted on a four-wheel cart, figured at the Paris Exhibition in 1881. The current was led to the motor by the rails and the wheels, and some metal boxes, also on wheels, where the dispatches were enclosed, were attached to it. Deprez's calculations showed that twelve horse-power would suffice for the transport of dispatches on the whole of the subterranean network of Paris; at the present moment the work done by the pneumatic post requires 120 horse-power.

We will finish this paragraph by describing an interesting application of electricity to railway traction, though it does not belong to the transmission of power to a distance. The important linen-bleaching establishment of P. Duchesne Fournet, at Breuil-en-Auge (Calvados) possesses a little railway for the transport of pieces of cloth, and for laying them out on the ground where they are every day exposed to the action of the sun. The locomotive is driven by a Siemens' dynamo-electric machine with a reverser, which is worked by Faure accumulators, placed in a tender attached to the locomotive. By moving the handle of a commutator, the driver can, at will, set the train going in one direction or the other, can regulate the speed, or put the motor in connexion with a roller, which serves to collect the cloth spread out on the ground. The accumulators are charged by the current of the Gramme machine which serves for lighting the workshop.

Electric traction has been enormously developed during the past five years in the United States of America. At the beginning of that period the subject was only in an experimental stage, whereas at the present time there are 1,500 miles of tram and railroad either actually worked by electricity or being constructed for electric working. No less than 180 towns possess one or more electrically worked lines, and these have a locomotive stock of 3,070 motor cars with an aggregate capacity of 60,000 horse-power.

In the majority of cases the power is generated by stationary engines and conveyed to the motor-cars by overhead conductors in the way shown at page 793 in the case of the Siemens electric tramway. One cause of the great development has been that American citizens do not object so strongly as we do on this side of the Atlantic to having their streets disfigured by the unsightly cables that are necessary. The electric pressure employed on tram lines is usually from 400 to 550 volts for tramcar work with starting

currents of from eighteen to twenty ampères on the level, increasing to twenty-five ampères on gradients; the average actual current employed whilst the tramcar is running is about ten ampères, the limit of speed allowed being about nine miles per hour. Twenty or more cars are frequently supplied with current by the same set of conductors, and from one generating station. But electric traction has also been applied to railways where the speed is not limited by the same considerations that apply to tramcars, and American engineers consider it possible to attain a speed of sixty miles an hour with a short train driven by electricity.

ELECTRIC RAIL AND TRAMWAYS IN THE UNITED STATES, 1ST SEPTEMBER, 1890.

	System.	Miles.	Motor cars.	Roads.	
Working.	United Electric Traction	56·1	110	19	
	National	55·5	67	8	
	Short	22·5	41	6	
	Edison (Sprague) . . .	516·4	1044	71	including one 50 miles long
	Thomson-Houston . .	581·9	783	68	,, ,, 112 ,, ,,
	Van Depœle	36·25	47	9	
	Storage Batteries . . .	28·5	12	3	
	B.-K.	18·5	10	1	
		1315·65	2114	185	
Under Construction.	United Electric Traction	2	4	1	
	National	17	15	2	
	Short	75	232	4	including one 55 miles long
	Edison (Sprague) . . .	313·4	293	27	,, ,, 200 ,, ,,
	Thomson-Houston. . .	319·75	417	35	,, ,, 118 ,, ,,
		727·15	961	69	

Total 2,042·8 miles, 3,075 motor cars, 254 roads.

§ 4.—*Applications of the Electric Transmission of Power in Mines.*

Electric machines are now being used for various purposes in mineral and coal mines. The installation made at the mines of Peronnière by the engineers Charousset and Bague is an example of this application of the transmission of power by electricity. It was necessary to move a winch placed at the depth of 600 yards in the mine at the top of an incline so as to bring the trucks of coal from one of the shafts 40 yards lower down, to

the level of the roadway. A Meyer horizontal steam-engine was placed outside one of the other shafts, situated at 1,300 yards from the winch; this supplied power to two Gramme machines by means of two pulleys, acting by friction on two other pulleys of compressed paper, which were attached to the axle of each machine. The speed of rotation of the two generators was 1,300 turns a minute. Two other Gramme machines, placed in the interior of the mine near the winch received the current produced by the first through two cables, uniting in each case the opposite terminals of the generator and the motor. The perfect insulation of the conducting wires is of great importance. This insulation, in the case we are describing, is easily obtained: the wires were covered with two layers of paraffined cotton; one layer one-fifth of an inch thick of gutta-percha; two twists of linen, and one twist of tarred cotton. To preserve the cotton envelope from damp and hot gases, Charousset and Bague soaked the cables in a very glutinous and insulating matter, formed of 57 parts of Norwegian tar, 38 of resin, and 5 of fat. This last precaution was only necessary in damp parts of the road. The conductors of these cables are formed of 16 wires of perfectly pure copper, of one twenty-fifth of an inch in diameter. The motors turn with a speed that varies between 0·6 and 0·9 of that of the generators. In these conditions, the winch can draw up 4 trucks of about 8 cwt. each in 160 seconds, thus accomplishing a useful work of 2,890 foot-pounds per second, the height being 43 yards. The steam-engine developed a power of 11,060 foot-pounds per second, and the practical efficiency is therefore a little more than 26 per cent. But if the efficiency of the Gramme motors and generators be considered, the electrical efficiency mounts to 61 per cent. The engineers who made this installation sum up in the following terms the conclusions resulting from observations made during the first six months:—"We think that electricity employed to transmit power (in mines) may advantageously replace, as regards efficiency, cost of installation, and maintenance, compressed air, and mechanical traction, especially in the following cases:—

(1) When the mine is not too full of fire damp.

(2) When there is a long distance between the source of electricity and the receiver.

(3) When the galleries, through which the power has to be

transmitted, have many turnings, and above all, when there is only one series of galleries and side shafts at right angles to make use of."

A very successful system of pumping and hauling by means of electric machines has been in use for over two years at the St. John's Colliery, Normanton. The plant installed at first was only intended to pump the water out of the mine, but the success was so marked that a duplicate plant was put down for the purpose of hauling. The dynamo that generates the current for the pumping motor is driven by an 80 horse-power steam engine on the bank, and is capable of giving a current of seventy ampères at 600 volts pressure when running at a speed of 450 revolutions per minute. This current is conveyed by a cable 1,000 yards long to the motor house at the bottom of the shaft. The cable consists of nineteen strands of copper wire heavily insulated and surrounded by a lead covering to protect it from the water and damp of the mine. The motor, which is similar to the dynamo, but with somewhat lighter field magnets, runs at 450 revolutions per minute, and drives a set of differential pumps at twenty-five revolutions per minute. These pumps lift 120 gallons of water per minute through a four-inch cast iron pipe 450 yards long, the total vertical height through which the water is raised being 900 feet. In spite of the fact that the pipe is too small for the quantity of water to flow easily, and thus causes an unnecessary waste of power in friction, the total efficiency of the arrangement of engine, dynamo, conductors, motor and pumps is 43·1 per cent. A similar dynamo and motor is used for haulage, and there is a duplicate set of pumps. The three rooms containing the motors, the pumps, and the hauling gear are alongside one another, and the mechanical arrangements are such that either motor can be coupled to either of the pumps or the hauling sheaves. A steel rope passing round the hauling sheaves drives two horizontal sheaves in the main road of the mine. Each of these sheaves in its turn drives an endless steel rope, and these two ropes are used for hauling from different parts of the mine and they can be started and stopped independently without stopping the motor. The arrangement is capable of hauling from 1,000 to 1,200 tons of coal per day of ten hours although the present output is only about 700 tons per day.

Electric motors are also being used now for driving rock drills

and coal-getting machinery. The machines carry a number of long augurs or drills which for coal getting are arranged in horizontal rows and deeply undercut the coal. Thus at Pittsburgh in the United States a machine which is driven by a three horse-power motor makes an undercut three inches high, thirty six inches wide, and forty-two inches deep in less than fifteen minutes. The machine and motor are mounted on a truck which can be easily moved by one man, and the whole apparatus weighs about 1,000 lbs. One man with such a machine will get as much coal in a day as twelve or fourteen pick miners.

We could multiply examples of this new and useful application of powerful electric generators transformed into motors, an application that the invention of the Gramme continuous current machine has rendered possible. We shall, however, only refer to the exhibits at the Palais de l'Industrie during the International Exhibition of Electricity in 1881. There, a multitude of machines of all sorts, lathes, machines for planing, plaiting, weaving, embroidering, sewing, &c., worked without ceasing, moved by an invisible power. But on this subject there is another question to be considered connected with the transmission of power, and to which we shall return when we have described the apparatus for electric lighting: we mean the distribution of electricity. Experiments were made in Bavaria on the line from Munich to Miesbach in 1884 by Marcel Deprez. The transmission of power between two identical Gramme machines, connected by a conducting wire of galvanized iron one-sixth of an inch in diameter has been made with a loss of less than 40 per cent. The distance between the two stations is 35 miles.

Since then power has been transmitted over considerable distances with most satisfactory results. It is now nothing extraordinary for an electric motor yielding from 200 to 300 horse-power to be worked by electric currents from a distant generator. At the present moment operations are begun to utilize on a still larger scale a portion of the enormous power now running to waste at the falls of Niagara.

CHAPTER XII.

ELECTRIC LIGHTING.

§ 1.—*Arc Lamps.*

THERE are two species of electric lamps, namely those in which the brilliant electric *arc* is employed, and those in which the light is due to the incandescence of a thin pencil or wire through which the current flows. The lamps of the first species are called *arc lamps*, whilst the second are called *glow lamps*. We shall deal with them separately.

ARC LAMPS.

The Voltaic *arc*, discovered by Davy, has been already described at p. 442. The general characteristics of it are therefore already known to the reader, who is aware that it consists of a sort of pale flame which is formed by first bringing together, in the electric circuit, the tips of two pencils of hard carbon and then separating them to about the sixteenth part of an inch. The tips of the carbons become white hot, and emit a dazzling light, usually needing to be toned down by the intervention of a semi-transparent shade. It is difficult and has hitherto been found impracticable to make arc lamps to work with currents of less than 4 ampères, consequently it is rare to find arc lamps designed to give light of less than 400 or 500 candle power, whilst a light equal to that of 1,000 or 2,000 candles is the regular and usual value for arc lamps such as are ordinarily constructed. For light-house work and search lights far more powerful arc lights are employed. Indeed the light of the arc lamp is, of all known artificial sources of illumination, by far the most intense.

Owing to the circumstance above-mentioned, arc lamps are in general unsuited for the illumination of interiors, save for very large buildings, such as factory sheds, warehouses, circuses, and exhibitions. For hotels, clubs, ships, shops, and dwelling-houses, glow lamps are commonly preferred.

In the design and construction of arc lamps the peculiarities of behaviour of the voltaic arc have to be considered, and provision made therefor. In the first place, a mechanism must be provided which will, when the light is required to be produced, automatically bring together the tips of the two carbon pencils and then draw them apart to the required distance. This action is called *striking* the arc. Secondly, as pointed out in Chapter XI., Book II., p. 442, the carbons slowly consume away, with the consequence that if after the arc has been once struck the carbon pencils were to be held immovable, the gap between them, across which the flame or arc plays, gradually lengthens. As it lengthens it offers a greater resistance to the passage of the electric current, and consequently unless provision is made to move one or both of the pencils gradually forward, there will arrive a moment when the electro-motive force of the source from which the current is supplied will no longer be able to maintain the flame over so long a gap, and it will go out. To avoid such an interruption in the light there must therefore be provided a mechanism to *feed* the arc by propelling one or both carbons mechanically forward in proportion to the consumption. And this feeding mechanism must work automatically.

Thirdly, in the event of extinction of the arc, the striking and feeding mechanisms must be so arranged as to come into operation so as to bring the tips of the pencils once more into actual contact and then re-strike the arc.

Fourthly, as pointed out on p. 442, the two carbons consume at unequal rates, partly in consequence of transfer of particles from the positive pole to the negative pole, partly because the two tips are generally not quite equally heated. When, as is usual, the wires are so arranged that the current *descends* through the arc from the top carbon to the bottom one, the top carbon becomes much the hotter; it wears away in a hollow form or *crater* at its tip, whilst the lower carbon becomes pointed. If the carbons are of the same size and quality the rate of consumption of the upper (positive) carbon is

very nearly twice as great as that of the lower (negative) carbon. It is however usual in arc lamps working with continuous currents to use for the upper carbon a pencil of a rather larger diameter and of a softer quality—sometimes with a core of soft carbon—than that which is used for the lower pencil. When alternating currents are used, however, carbons of similar quality are used at each pole, and the consumption is very nearly equal. As a consequence of the inequality of consumption whenever continuous currents are used, it is obvious that the position of the luminous arc will not remain constant unless the positive carbon is fed forward at a different rate from that at which the negative carbon is fed. In many cases this is of no consequence, but wherever the fixity of position of the light is important, as in the case of arc lamps used in combination with lenses or mirrors, as in light-house work, or for search-lights on board ship, or in magic lanterns, then it is very essential that the luminous arc should keep its proper focus. Hence there must in these cases be added a *focussing* mechanism. This usually consists of a differential rack-work, or of cords passing over a differential pulley. In the case of lamps for lighting streets, open spaces, mines, or factory sheds, there is no necessity for focus-keeping, and in the great majority of arc-lamps, as we shall see, the lower carbon is simply fixed once for all, whilst the upper carbon slowly descends as required.

Fifthly, whenever more arc lamps than one are being worked in a circuit, it is necessary to provide some means to prevent all the lamps from being extinguished if by any mischance any one of the lamps goes out. It is requisite to provide either a mechanism which shall, on the extinction of a lamp, *change-over* the connexions to another pair of carbons in place of those which are consumed, or else a mechanism to *cut-out* from the circuit the lamp which has ceased to act, the current being sent through a by-pass wire.

That all these actions should be automatic it is essential that they should be controlled by the action of the current itself. For example, the action called striking the arc ought to be accomplished by some electro-mechanical device worked by the current that flows through the lamp. As we shall see, an electromagnet, the coils of which are inserted in the path of the current, may accomplish this, as the iron armature will be pulled by the electromagnet as soon as the current passes through the lamp.

But there is another theoretical point of even greater importance, and it is quite easily understood. In several places in this book it is pointed out that electric work is always the product of two factors. In the case of lamps, the work done per second in maintaining the light is expressed also as the product. The two factors are in this case the strength of the current (*i.e.* the quantity of ampères flowing through the arc) and the difference of pressure, or potential, between the terminals of the lamp (*i.e.* the number of volts from one terminal to the other). If this product can be kept constant while the lamp is burning, then the work done in every second will be equal, and the lamp will necessarily burn with a steady light.

Now, as mentioned in the preceding chapter, it is usual to manage the supply of electricity on the large scale on one of two methods. In one method (as is usual for glow-lamps) the currents, large or small, are distributed at constant pressure (or potential), by two sets of mains laid side by side, with pairs of wires branching off, a separate pair of branches for each lamp. In the other case there is only one circuit, the wire going from the dynamos, first to one lamp, then on to the next, and so forth, returning finally to the negative terminal of the dynamo. In this latter case the lamps are all in series, the same current passes through all the lamps; and consequently care must be taken so to arrange and regulate the dynamo that it shall keep the current at constant strength whether many lamps or few lamps are intercalated in the circuit. In the former case the dynamo is responsible for keeping the potential of the distributing network of mains constant, no matter how much current is being drawn off to light the lamps. In the latter case the dynamo is responsible for keeping the current in the circuit constant no matter how many lamps that current has to be forced through. Let it be assumed that in each case the dynamo does its work properly: let us then see what remains for the arc lamp to do in the way of regulation.

In the case of distribution at constant potential, each arc lamp will have to regulate its own current. If it keeps its own current constant and the dynamo keeps the potential constant, then clearly the product of current and potential will be constant, and the light will be constant too.

In the case of distribution with constant current each arc lamp

must be so designed as to regulate its own potential. For if it keeps its own potential constant and the dynamo keeps the current constant then the product of current and potential will be constant as required. We shall see presently how this is done; but it is obvious that henceforth we may group arc lamps in two classes: those that are intended to work at constant potential on a network of mains along with glow lamps; and those that are intended to be worked in series with one another with a constant current.

This classification entirely supersedes the old classification of lamps into monophotal and polyphotal, a classification which is misleading.

§ 2.—*Early forms of Arc Lamp.*

In 1844 Leon Foucault conceived the happy notion of substituting for charcoal, pencils sawn from the hard carbon which is found encrusting gas-retorts. This suggestion was found to be so great an improvement that it gave an immediate impetus to electric lighting. In recent years still better forms of pencil have been produced, finely ground carbon being made into a paste moulded under hydraulic pressure, and subsequently soaked in carbonaceous matter and baked at a white heat.

In 1846 W. E. Staite devised a rude lamp in which two pencils of carbon were held obliquely against a distance-piece of lime or other infusible non-conductor. In 1847 and 1848 the same inventor devised several perfected forms of lamp in which the mechanical motion of the parts was governed automatically by electromagnetic action, a coil introduced into the circuit of the lamp being made to attract an iron core, and so regulate the action. In 1849 Foucault constructed a lamp in which an electromagnet regulated the action by the attraction which it exercised upon a pivoted armature which was held back by a retractile spring. When the current flowing through the lamp grew weak this spring pulled back the armature and allowed a train of wheels, driven by a coiled spring, to run round and so "feed" the carbons to the arc. In this early form the pencils were horizontal and were supported on little carriages which ran on wheels toward one another. The clockwork mechanism and the regulating electro-

magnet and spring were retained long after the horizontal arrangement of carbons had been abandoned. A year or two later the famous optician Duboscq constructed a compact clockwork mechanism, and

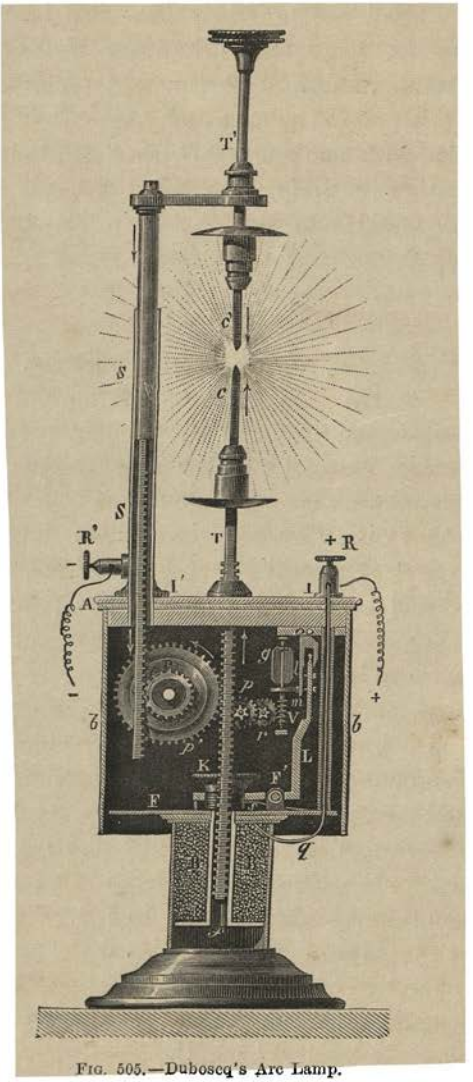

FIG. 505.—Duboscq's Arc Lamp.

later Duboscq and Foucault together produced a lamp which for a long time remained unequalled for use in the optical lantern.

Duboscq's lamp, which is represented in Fig. 505, is not designed

to work under either of the standard conditions of constant potential or constant current, but was always worked singly with a battery of cells, for example forty or fifty cells of the Grove or Bunsen type. Duboscq's object being mainly to obtain a lamp suitable for optical applications, it was designed as a focussing lamp. Unlike the ordinary modern practice the current in this lamp was caused to ascend the arc. The carbon pencils *c* and *c'* are clamped in appropriate holders. The current generated by the consumption of zinc in the cells traverses the acid fluids, then ascends to the positive terminal of the battery, passes thence along the positive leading wire and enters the lamp by the terminal R. From this point it descends by an insulated wire *q* which leads it to the coil of the hollow electromagnet B. After circulating around this coil it enters the stem T of the lower carbon holder, and flows up through the carbon points, and descending the support S it reaches the negative terminal R', whence it returns by the other wire to the negative pole of the battery. The lower carbon-holders stand upon a rod on which a double rack is cut. The stem which carries the cross-head and upper carbon-holder slides through a vertical tube S, and also has a rack cut on its edge. These racks gear into two toothed wheels of different sizes that are fixed to a barrel containing a coiled spring which can be wound up from the outside of the case that holds the mechanism. The uncoiling of this spring tends to bring the carbon tips together, and moves the positive carbon forward at twice the rate that it moves the negative carbon. Save however for a little freedom of play, the carbons cannot move without driving the train of wheels *p p'*, the last member of which is a fly *g* worked by a worm V. This fly, however, can be caught and arrested by the interposition of a detent attached to a bent lever L pivoted at F'. The lower arm of this bent lever is held up below by a spring *s*, and it bears an iron nut K through which there is a hole to admit the tail of the lower carbon-holder. The action of the lamp is as follows: Before the battery is joined to the circuit, when therefore no current flows, the spring *s* holds up K and pushes back L from the fly. The wheels therefore are not locked and the coiled spring drives them round until motion is stopped by the touching together of the two carbons. In this state things remain until the current is turned on. As soon as this is done, the current, circulating round the coil B of the electromagnet, causes it to pull powerfully at K, which is

drawn down, and the lever L locks the fly. So, as the arc gradually forms itself and burns away, the carbons remain apart: but as the arc offers an increasing resistance to the flow of the current the latter grows weaker and weaker until a moment comes when the electromagnet no longer pulls at K so strongly and the spring *s* pushes it up, releasing the train of wheels. The carbons approach a little, but as they approach the current grows stronger again, owing to the lessening of the resistance as the arc is shortened, and a moment arrives when the iron nut K is once more attracted, and the clockwork locked by L, until the arc has again burned long, when the same action repeats itself. The feeding is thus accomplished automatically by the weakening of the current.

Fig. 506 represents the more perfect lamp of Foucault and Duboscq. As in Duboscq's earlier form the carbon holder rods are provided with racks, and both are driven by the toothed wheels between them. A coiled spring in the barrel G, as in Duboscq's lamp, tends to bring them together. This barrel, however, has a third toothed wheel upon it which is geared into another, on the right, which in turn is connected to another below it. This other is geared to a double train of wheels each of which ends in a star wheel. These are marked *o* and *o'*. One of these trains of wheels is driven by a powerful spring coiled in a barrel L; and a most ingenious piece of epicyclic gearing, known as a compound sun-and-planet motion, shown in part at *s*, is so arranged that it allows either train of wheels to act. Between the two star wheels stands a stem T pivoted at the bottom and armed at the top with a double detent. When it stands exactly vertical its detents lock both the star wheels so that neither train can revolve. If it moves to the right it still locks *o'*, but releases *o*. Then the left-hand train is free, and the spring in G drives this train and brings the carbons together. If however T tilts over to the left, *o* is locked and *o'* is released. In this case the right-hand train of wheels is free, and it is driven round by the spring in L, which also drives a wheel which drives the planet-wheel of the combination at *s*, and so in turn drives the wheel above *s* and forces the carbons apart; in doing this it of course winds up to a small extent the weaker spring in G. Hence it is clear that the carbons can be made either to approach towards one another, or to recede at will by merely altering the position of the lever T. The whole problem of making the lamp

automatic then resolves itself into this: how to make the current

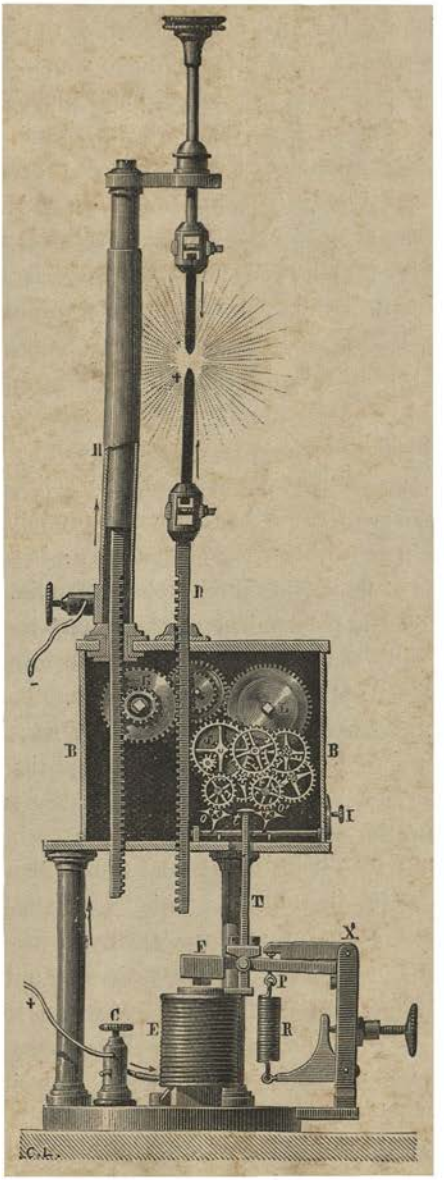

FIG. 506.—The Foucault-Duboscq Arc Lamp.

work the lever T at the proper time, tilting it to right or left as

required. This is accomplished by the electric mechanism situated on the base of the apparatus. It consists of a small electromagnet E, the coils of which are included in the circuit of the lamp. Above the poles of this electromagnet lies its armature F, an iron bar seen end-on in the figure. It is attached to a horizontal pivoted lever, the other end of which lies to the right. This lever and the upright lever T are screwed rigidly together, so that as F rises or falls, T moves to right or left respectively. The horizontal lever is held down in a peculiar manner. Upon it there presses a lever X, pivoted on the right to the upright frame, and pulled downwards by a link and an adjustable spring R. This link passes at P through a slot in the horizontal lever. The lever X has its under side curved to a particular shape. The object of this device is to give the pull of the spring greater power as the armature of the electromagnet approaches; for the pull of the electromagnet is very unequal, being very great at short distances, but falling off as the distance increases. This ingenious contrivance of a rocking-lever for making the spring compensate, is known as a *repartiteur* or *equalizer:* it was invented some years before by the famous conjurer Robert Houdin.

The action of the mechanism of this lamp is as follows. The carbons are initially at rest in contact with one another, being driven together by the coiled spring in the barrel G. Because they touch there is an uninterrupted path for the current, which, when the battery circuit is completed will flow in through the positive terminal C, round the electromagnet E, up the frame of the lamp to the lower carbon holder, up the carbons, down the upper carbon-holder and its supporting tube (which is insulated from the body of the lamp), and so to the negative terminal screw. This current, being a strong one, causes the electromagnet to pull powerfully at its armature, and it tilts the vertical lever T over to the left, thereby unlocking the star-wheel o' and allowing the right-hand train of wheels to turn, parting the carbons and so striking the arc. When the carbons have thus parted the arc will offer some resistance, and the current will diminish somewhat, so that the electromagnet will pull less forcibly, and the spring of the equalizer will begin to pull the armature back and will bring the lever T upright, locking the wheel o'. In this state of things both trains are locked: and they will continue so until, by reason of further consumption of the carbons, the resistance of the arc has

still further increased, and the current still further diminished, when the spring of the equalizer will pull the lever T still further over and will momentarily unlock *o*, allowing the other trains of wheels to act, feeding the carbons a little into the arc. This will only be momentarily, for as the carbons come nearer together the current grows stronger again, and the electromagnet pulls T upright, once more locking *o*, until the next time when the arc requires to be fed. When the lamp is in good adjustment, this will occur pretty regularly about twice every minute, the feeding motion being small and frequent. The variations in the light will thus of course be less pronounced than if the feeding motion were of larger amount at longer intervals. This lamp was very widely used for optical purposes at one time, but it does not answer well for use in industrial lighting. The mechanism is delicate, and it is not successful when the condition of supply of electricity is either at constant potential or with constant current. Nevertheless the lamp is remarkable: it contains a host of ingenious details beside these which have already been described.

Serrin's Lamp, Fig. 507, which dates from 1859, was largely used, and is still used, for the lighthouse service both in France and in Great Britain. In this lamp the upper carbon-holder A B is provided at its lower end with a toothed rack gearing into the toothed wheel F. This upper carbon-holder is massive and by its weight in descending drives the wheel F and the attached train of wheels and also at the same time turns the pulley G, so winding up the chain A and raising the lower carbon. It will thus be seen that the two carbons will come together by the mere action of gravity if the wheel-work is allowed to revolve. As a matter of fact the wheel-work is free so long as no electric current is following, so that the carbons naturally touch one another in readiness for the current to be turned on. The electrical circuit through the lamp takes the following course. The current enters by the positive terminal at the back of the lamp, not shown in the figure, and passes thence to the metallic upright tube through which the upper carbon-holder slides: thence it enters the upper carbon-holder A B, crosses by the metal rods at the top to C, so arriving at the top carbon. Thence it passes downwards through the arc to the lower carbon, and down the carbon-holder K K which is itself supported upon a sleeve which is insulated from the mechanism

of the lamp. From the lower end of K the current is conducted to

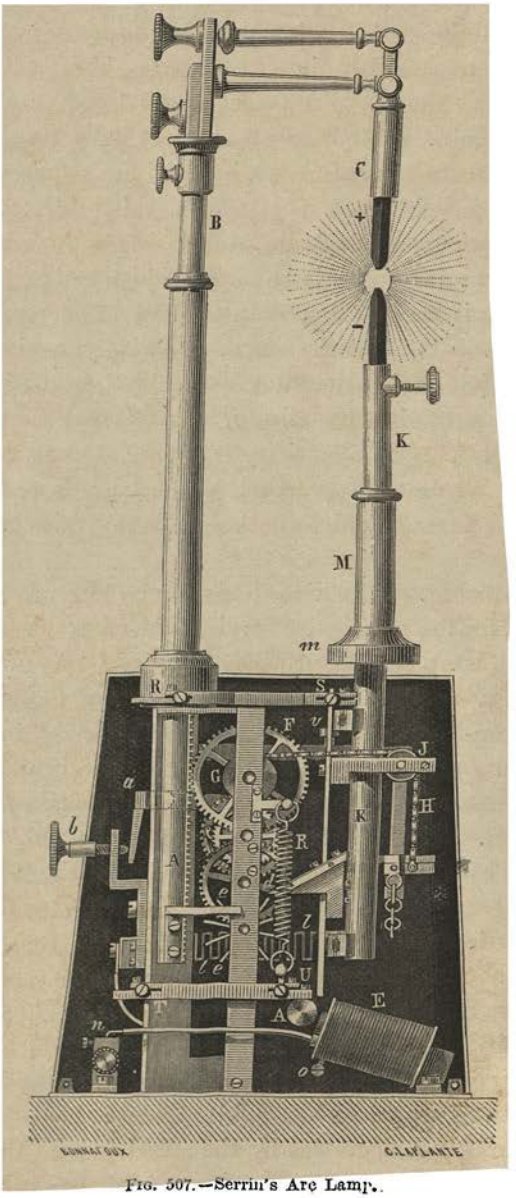

FIG. 507.—Serrin's Arc Lamp.

the left by means of a strip of copper *l*, which, in order to be flexible, is

bent in a zig-zag shape, and is clamped at the left hand end to a copper wire by a screw which is screwed into an insulating block. The copper wire turns down and returns to the right, carrying the current to the electromagnet E which governs the action of the mechanism. Having circulated around the coils of this electromagnet the current returns by another wire to the left and terminates at *n*, which is the negative terminal of the lamp. The action is as follows:—As soon as the current begins to flow through the lamp it magnetises the core of the electromagnet E, which at once pulls strongly at the iron armature A (a round bar seen end-ways) above it, and attracts it down to the position shown in the cut. The armature A is mounted on a peculiar jointed framework, known as the parallelogram. It consists of two horizontal bars R S and T U joined by a third upright bar S U. The horizontal bars have pivots at R and T secured into the upright fixed framework of the mechanism. When A is pulled down the right hand side of the parallelogram S U descends, but keeps always in a vertical position. A long and strong spiral spring, hooked at the top end to the fixed framework, and at the bottom end to the lever T U near its extremity U, tends to lift up the parallelogram whenever the electromagnet is not pulling it down. Now the downward pull of the electromagnet accomplishes two things. Firstly, since the lower carbon-holder passes through a sleeve mounted on the bar S U, the descent of the parallelogram pulls down the lower carbon through a small distance, and "strikes" the arc. Secondly, it locks the wheel-work. This is done by means of a triangular-shaped piece attached to the middle of the bar S U: the tip *d* of this triangular piece acting as a detent which catches between the teeth of the star-wheel *e*. As this star-wheel constitutes the fourth member of the train of wheels driven by the descent of the rack, it is clear that if it is locked the whole of the wheels must stand still, and the rack cannot descend. Hence the upper carbon-holder is held up until such time as the consumption of the tips of the carbon-pencils renders the "feeding" action necessary. Suppose the tips have consumed away for some moments—say for half a minute—the gap across which the luminous arc plays will have lengthened; and the arc itself will, in consequence, offer to the flow of current a greater resistance than at first. This increased resistance in the arc will cut down the flow of current slightly, and consequently the pull of the electromagnet will be

weakened. There will come a moment when as the electromagnet gradually weakens the upward pull of the spiral spring will prevail and the parallelogram will rise. This will release the wheelwork, which will run round a little way, allowing the upper carbon to descend, perhaps by $\frac{1}{100}$ of an inch, and in its descent pull up the lower carbon by about half that amount. This will shorten the arc, decrease its resistance and so allow the current again to increase to its normal value when the wheel-work will again be locked by the pull of the electromagnet until, after another interval, feeding again becomes necessary. The pulley G has a diameter about half that of the pitch circle of the toothed wheel F, so as to ensure that the motion of the lower (negative) carbon is about half as great as that of the upper (positive) carbon. The lamp is therefore a "focussing" lamp. There is a ratchet wheel attached to the second wheel of the train, the object of which is to allow the upper carbon-holder to be pushed up by hand, even though the star-wheel is locked, so as to admit of replacing the stumps of the burned carbon pencils by long new pencils.

Messrs Siemens and Halske, of Berlin, have constructed an arc lamp invented by Hefner Alteneck to work with his magneto-electric machine. This lamp, which is widely employed in Germany, is represented in Fig 508. The carbon-holders, which are both movable, are geared by racks on their respective rods to two toothed wheels of different sizes, mechanically fixed together on the same axis but electrically separated from one another by a collar of insulating material. By its weight, the upper carbon-holder A brings down the positive carbon, at the same time raising the negative carbon. The contact of the tips establishes a path for the current which, flowing round the electromagnet E, causes it to attract an armature M, itself the prolongation of a bent lever L which is pivoted at Y. A pawl or click Q is set in operation by the movement of the extremity of the stem L, drives the ratchet wheel I and by its means actuates the wheel-work of the mechanism, so producing the required separation of the carbon points, and striking the arc. At the same moment however contact is established at X, the current is shunted out of the coils of the electromagnet, the greater part of it going through the by-pass route thus established. The electromagnet consequently relaxes its pull on the armature, which rises to its original position.

But in so doing the contact is destroyed at X; the current once more flows round the electromagnet; a new attraction takes place, and so on. When the current is greatly weakened, the driving pawl is completely lifted off, for a brief instant, from the ratchet wheel, so

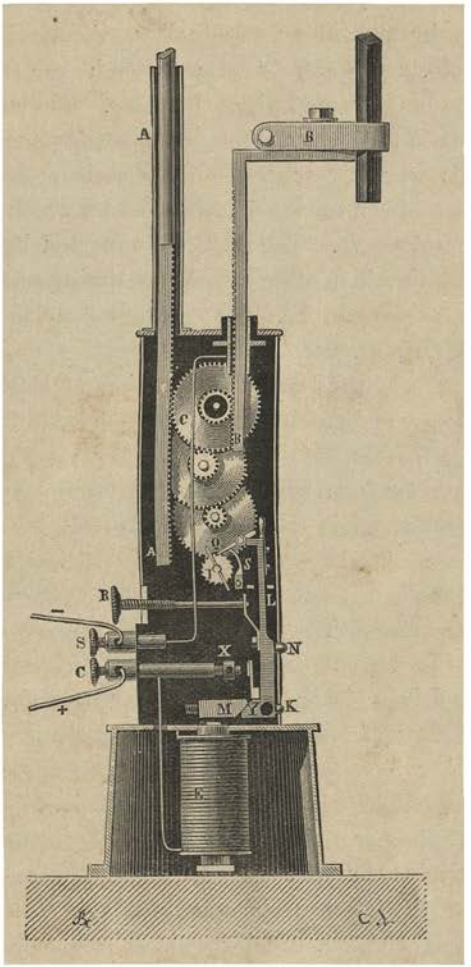

FIG. 508.—Siemens' "Contact" Lamp.

that the train of wheels is free to go round, the carbons approaching one another, and thus "feeding" the arc. This lamp is therefore one in which gravity brings the carbons together, and in which the electromagnet, acting on the ratchet wheel by the pawls, drives

them asunder to strike the arc, afterwards governing the feeding. The pawl then drives the wheels against the force of gravity in order to strike the arc: it permits the wheels to turn in obedience to gravity, in the opposite direction, when feeding is necessary.

The path of the current through the lamp is as follows. The current enters by the lower terminal C, thence it flows, either through the electromagnet, or else through the short-circuiting contact X to the brass framework of the lamp. Through this it finds its way upwards to the tube A through which the upper carbon-holder passes. In this way it reaches the upper carbon; descends through the arc, and passes down the lower carbon-holder which moves through an insulated metal sleeve. The latter is connected by a return wire to the negative terminal screw S. A regulating-screw R allows of the adjustment of the power of the counterbalancing spring to the strength of the current.

Among the arc lamps based on the action of electromagnets, we may mention those of Fontaine, Lontin, Gramme, Bürgin, Crompton, Brockie, Brush, Weston, Maxim, and Thomson-Houston. We see by this list, which is far from being complete, how many systems there are, the object of which is the production of electric light, or rather of the voltaic arc. We have only passed in review one class of arc lamps. In all the lamps so far described, the action is based on the weakening of the strength of the current as the arc lengthens: and in all of them the current acts, by means of an electromagnet, on a train of wheels driven either by a spring or by gravity.

In another class of lamps the current passes through a solenoïd the iron core of which governs the travel of one or both carbons. Such is the principle of the apparatus designed, in 1848, by Archereau. The upper carbon being fixed, the action of a suitable counterpoise tended to raise the lower carbon as its point was consumed. But the lower carbon was itself also attached to an iron core which hung within a tubular coil, or solenoïd, through which the current flowed on its way through the circuit of the lamp. The action of this solenoïd attracting the iron core, was to hold the carbons apart. The same fundamental idea has led in recent years to the invention of the "Pilsen" arc lamp, in which the iron cores are tapered with the object of obtaining a longer and more uniform travel.

In the Jaspar arc lamp (Fig. 509), as in the earlier form of Archereau, the action of a solenoïd produces and maintains the separation of the carbons. But the positive one is not fixed, it tends to descend by the weight of the rod which supports it; this latter, at its lower end, pulls at a cord running in the groove of a pulley R,

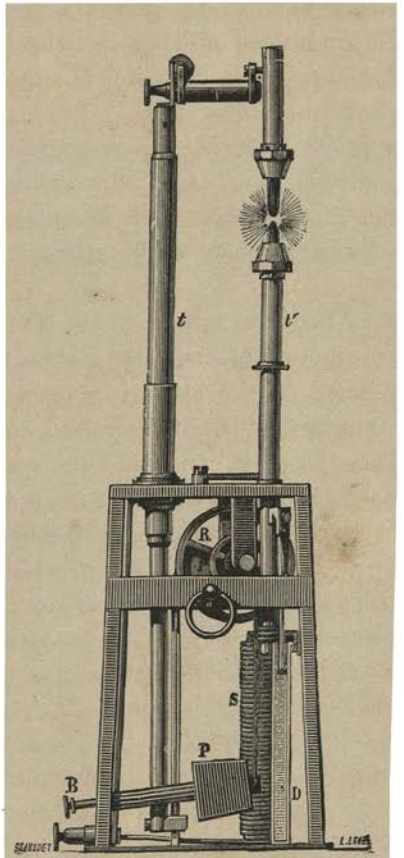

FIG. 509.—Jaspar Arc Lamp

which tends to turn in a direction, as seen in the cut, contrary to that of the hands of a watch. A second pulley, half the size, turns solidly with the first, and by means of a cord attached to the holder of the negative carbon tends to raise it half as far as the positive one has descended, so that the position of the luminous point remains the same. The distance between these two carbon points is also

regulated in the manner described, by the attraction of the solenoïds on the soft iron plunger attached below the negative carbon. Equilibrium between the two opposite forces which tend—one to bring together, the other to separate the carbons, is obtained by the aid of a counterpoise placed on an almost horizontal lever, which can be shifted along the lever by means of a handle. It is also possible to place the mechanism above the arc instead of below it. In all hanging-lamps, which are required to throw their light downwards, the mechanism is preferably placed above.

Gaiffe's arc lamp has two movable carbon-holders, geared together so as to keep the luminous point fixed at a constant focus; but in this lamp the action of the wheel-work is governed—not by an electromagnet, but by a solenoïd which attracts a movable iron plunger.

Carré's lamp (Fig. 510), is, according to Du Moncel, an ingenious improvement on the regulators of Archereau and Gaiffe. The electromagnetic action is based on the attractive effects of solenoïds, as in these regulators, but in the present case the core of the solenoïd does not itself perform the work of moving the carbon-holders. As in the case of the Serrin lamp, the weight of the upper carbon-holder drives the mechanism; the holders being geared by racks to a clockwork train the last member of which is a fly *t*, which can be stopped by a detent governed by the core of the solenoïd. The latter consists of two curved coils B B, into which enter the extremities of an S-shaped core of soft iron A A′, which turns on a pivot C in the middle. A double system of opposing springs *r r′*, furnished with an adjusting screw V, conveniently regulates the force opposing the attraction of the coils. The current which furnishes the voltaic arc traverses the two coils, and according as it is more or less strong, the iron spindle is more or less attracted up into the interior of the coils, causing a movement of the detent or releasing it when the current has been weakened by the too great increase in the length of the arc. The principal advantage of Carré's device is that the moving part is very light and dead-beat in its action, so that the lamp feeds at small intervals, and does not overfeed.

Brush's arc lamp is based, like the preceding ones, on the attraction of a solenoïd. (Fig. 511 shows an early form of this lamp.) In the inside of the coil, which is supported by a horizontal arm *b*,

there moves a cylindrical hollow spindle of soft iron *d*, traversed by the copper rod *ff* of the upper carbon-holder. Before the current passes, the two carbon-points *k k* are in contact; but when the current is turned on it circulates round the coils of the electromagnet A and

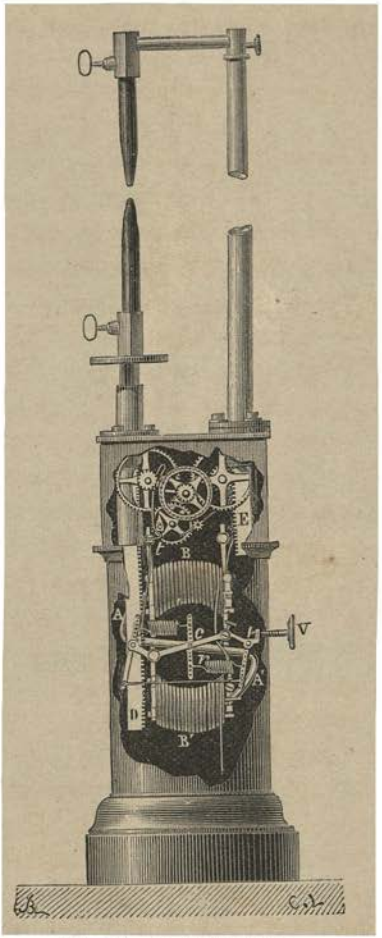

FIG. 510.—Carré's Arc Lamp.

the magnetic core *d* is raised; a hook *l* which it carries raises at the same time a collar *h*, on the copper rod *ff*, which it lifts, so that the upper carbon is drawn away from the lower one, and the arc is struck. Gradually the burning away of the carbons increases

their distance apart, and, when a certain limit is passed, the weakening of the current lessens the attraction of the electromagnet; the iron core falls slightly, and with it the collar and the upper rod. Thus the carbons are brought nearer and the current increases, holding the upper carbon in its new position until the arc again lengthens.

In Bürgin's lamp (Fig. 512) the lower carbon B is fixed, and the

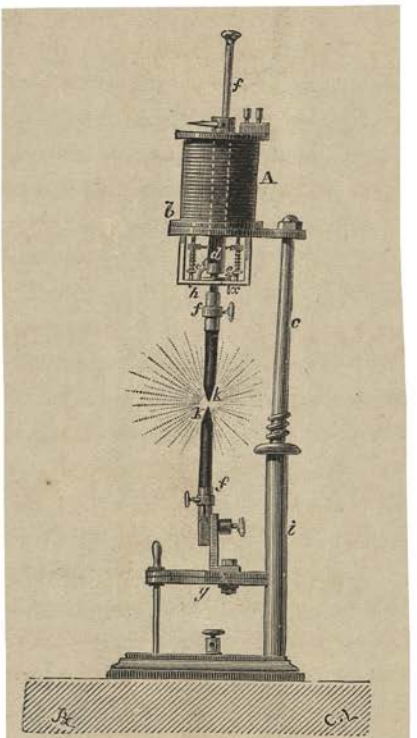

FIG. 511.—Brush's Arc Lamp.

movement of the upper carbon A, is controlled by means of a brake-wheel R. The axis of this brake-wheel is carried by the vertical side of a movable parallelogram such as is used in the Serrin lamp, and this side, made of soft iron, is the armature of the electromagnet EE. The link motion is so arranged that when the armature is attracted the movable side of the parallelogram is raised and with it the brake-wheel R. On the axis of R there is a smaller wheel round

which a chain passes and supports the weight of the upper carbon. When the wheel R is raised by the attraction of the armature, its circumference is pressed against a spring, which prevents it from turning round; the upper carbon is therefore raised with it and the

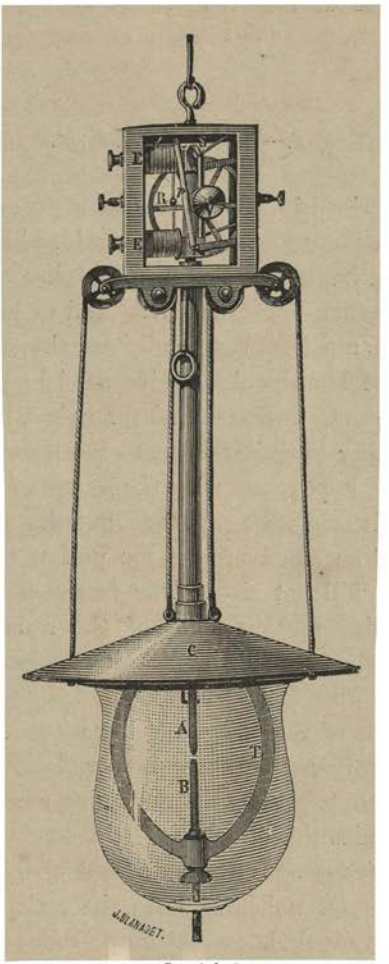

FIG. 512.—Bürgin's Arc Lamp.

arc is "struck." As the length of the arc increases the current diminishes, and the attraction of the electromagnet EE for its armature weakens. Eventually the armature is drawn a little distance from the magnet by the weight of the wheels and carbon

which it supports; the brake-wheel R is then slightly released from the pressure of the spring and the upper carbon moves downwards, thus shortening the arc. The current then increases, the armature is again attracted, and the wheel R braked. Thus as the carbons burn away the upper carbon is fed forward from time to time.

§ 2.—*Series Arc Lamps.*

The lamps described in the last section are mostly intended to be run singly; we have now to describe the various kinds of mechanism and apparatus that have been designed to allow many lamps to be run from a single generator of electricity and to examine how far the different arrangements fulfil the conditions already laid down. We first deal with those lamps which are intended to be run in series, *i.e.* those in which the same current is led through all the lamps passing from one to the other until it returns to the generator. We assume that this current is kept constant by the source of supply and it is at once evident that it cannot be used for regulating since if it be passed round the coils of an electromagnet the pull of this magnet on any armature or core will not alter. The factor of the electric power which changes with the variations of the resistance of the arc, is the potential difference, and therefore if we place an electromagnet in a shunt circuit with respect to the arc of any particular lamp, the current in the coils of this magnet will vary as the arc changes in resistance and by utilizing the consequent variation in the pull of the magnet it is possible to actuate the regulating mechanism.

In order to utilize this principle Lontin modified the Serrin lamp already described (page 812) by altering the electrical connections so that the electromagnet which regulates the action, instead of being placed in the main circuit, is connected as a shunt across the arc. The arrangement is diagrammatically sketched in Fig. 513. CD is the lever bearing the armature M, and S is the coil of the electromagnet. The current which enters at the positive terminal divides into two parts, the greater portion passing along CD and through the arc AB to the negative terminal; the other portion passes round the coils of S and eventually rejoins the first current at the negative terminal.

When, in consequence of the separation of the carbon points, the resistance in the arc increases, the main current CDAB is weakened, whilst on the contrary the shunt current CSB increases, till the increase is sufficient for the coil to attract the armature M whose movement actuates the mechanism and causes the carbon-points to approach one another.

In Lontin's lamp the normal position of the armature is such that the mechanism is held clutched, and is disengaged only when the arc is lengthened by the burning away of the carbons. In a shunt regulator it is not the variations of the current through the arc which actuate the mechanism, but only those of the shunt current; and therefore the different lamps in the generator circuit are independent of each other. Thus a dozen Lontin lamps in series can be placed

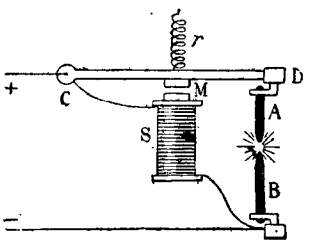

FIG. 513.—Regulation of a Series Arc Lamp.

on the same circuit, and fed by one machine. By using as a generator one of the machines which we shall hereafter describe, thirty-one of these lamps have been connected in series, to illuminate the Lyons-Mediterranean railway station at Paris.

Among the arc lamps based on this shunt principle we may mention those of Gramme, Mersanne, Gerard, Cance, and Hippolyte Fontaine.

Another category of series regulators comprises the differential lamps, of which that of Siemens is the type. The principle of these lamps consists in the difference of action of two solenoïds, one of which, with a thick wire, is placed on the main circuit, whilst the other with a fine wire is placed in a shunt circuit across the arc. The diagram in Fig. 514 shows how the lamps of this system are controlled. S and S′ are the two solenoïds in question. The first receives the

main current, which passes through the arc between the two carbons A and B. The second, the resistance of which is much greater, receives a current which is considerably less. A cylinder of soft iron C C′ has one end introduced into one of these coils and the other end into the other. This cylinder carries a lever, which oscillates about the point O according as the attraction of the solenoïd S is stronger or weaker than that of the solenoïd S′. The lever is rigidly connected to the positive carbon-holder, and preserves a horizontal, or equilibrium, position when the arc is burning steadily and when the separation of the carbon is normal. But, by their consumption, the length of the arc and its resistance increases, in which case the action of S on the piece of soft iron diminishes, whilst that of S′ increases,

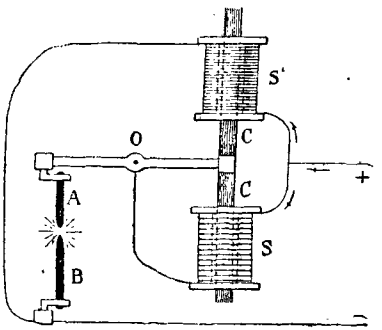

FIG. 514.—Principle of Differential Lamps.

since the main current is thereby weakened, and the shunt current increased. The soft iron cylinder is attracted upwards, and the lever moves so as to lower the upper carbon. This broadly explains the principles underlying the regulation of all differential lamps.

In Siemens's differential lamp, when the action of the shunt coil on the soft iron is greater than that of the other coil, a catch, which locks some clockwork, is let go, and the upper carbon-holder is then free to descend by its own weight; the approach of the carbons is thus only made from the positive side, the lower carbon being fixed. The result is therefore a continuous lowering of the luminous point; but the inconvenience is small, because the mechanism is placed above the arc, and moreover, the regulation being made almost without intermission, the change of position of the light is gradual. On the other

hand, the advantage of this gradual movement of the carbons is great, for it contributes to the steadiness of the light. The same machine can feed as many as twenty lights, each of which has an intensity of 250 standard candles.

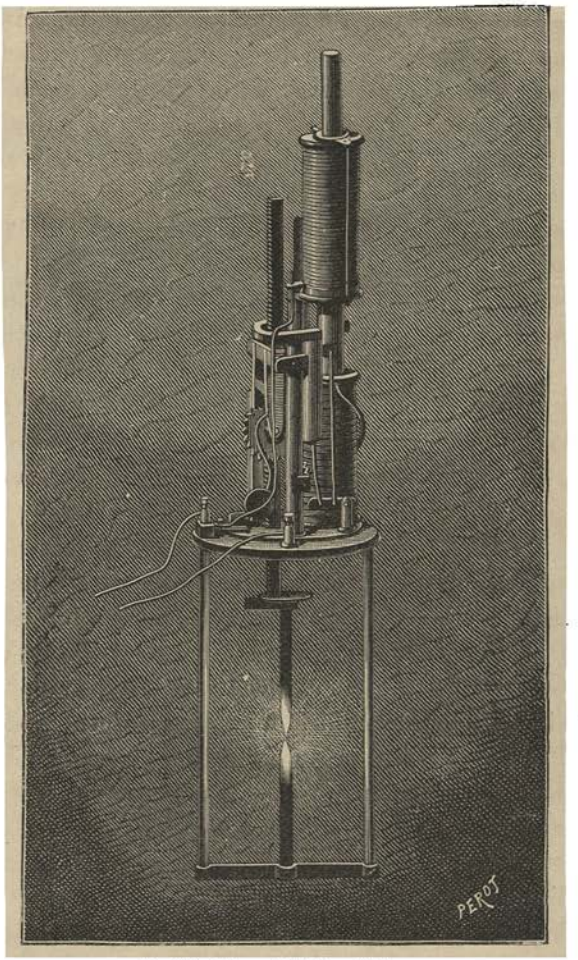

FIG. 515—Siemens's Differential Lamp

Among the differential arc lamps are Brush's and Weston's which are based on the same principle as the Siemens' lamp. We have already described the Brush lamp without directing attention to the character which ranges it among the differential apparatus.

The coil which encloses in the interior the magnetic spindle, the movement of which determines that of the upper carbon-holder, is not simple. It is formed of two independent coils, wound in inverse directions: one of these coils, with short and thick wire, carries the main current; the other, the wire of which is fine and long, is placed as a shunt across the two terminals of the apparatus. As the direction of the currents which act on the spindle of soft iron is contrary in the two wires, it is the difference of their actions which sometimes raises and sometimes lowers it, determining thus the regulation of the distance of the carbon-points and consequently that of the luminous arc itself.

Weston's lamp is very like Brush's; it incloses, like it, a solenoïd with a double coil of wires.

In Gerard's lamp the two pairs of carbons are placed together, above the position of the luminous point; the carbons thus descend by their own weight. The two pairs of carbons forming the poles are separated before the circuit is closed; the necessary approach of the carbons is produced by an electromagnet with a very fine wire, connected in shunt, which becomes inactive as soon as the arc is produced, since the current then passes almost entirely through the carbons.

The carbon plate lamp of Wallace Farmer was designed as a factory lamp, to run for long periods of time, without fresh trimming. Two large plates of carbon are placed one above the other. The lower plate is fixed, and the upper one is supported by the armature of a small electromagnet which raises it, as soon as the current passes. The arc forms at the part of the edge where the carbons are last in contact, and moves about as the combustion proceeds. The plates approach, and the arc shifts to another point. The duration of a single pair of plates is about 48 hours.

In Solignac's lamp the arrangement is at once very simple and very original. The carbons are arranged almost horizontally and in the same plane; by the action of two drums on the chains which are rolled round two pulleys fixed at the extremities of the carbons, they tend to approach each other steadily as their ends become used up by combustion. The current is transmitted by two slides which serve as a guide to the carbons, and the portion of carbon traversed by it before the arc is reached is thus limited to one or two centimetres.

The carbons are furnished underneath with little glass rods, the ends of which near the arc rest against some nickel hammers; in this way the approach of the poles is limited. When the arc increases, the heat of the incandescent part of the carbon is enough to soften the ends of the rods, which then bend, and thus permit the carbons to approach nearer. The inventor says that with a generating machine of one-horse power this lamp gives a light the intensity of which is equal to 950 standard candles, and with three-horse power six lamps can be maintained in the same circuit.

A form of lamp which has become deservedly popular of late is that known as the Brockie-Pell, Figs. 517 and 518.

It has won its way to the front as being essentially an engineer's lamp, the design and construction being such as an engineer would produce, not such as a clockmaker would devise. It agrees with

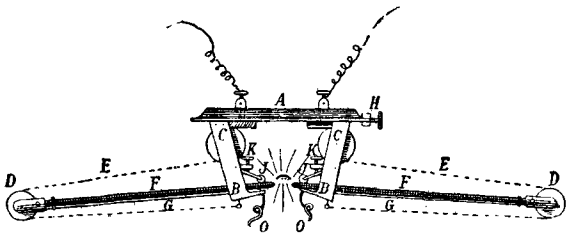

FIG. 516.—Solignacs' Lamp.

most of the commercial lamps in having as its motive power the weight of the descending upper carbon and its holder. A rack cut on the holder-rod drives a single wheel which has a smooth projecting rim or clutch-wheel. Fig. 517 gives a general view of the lamp. Against the rim of the clutch-wheel there can be pressed a brake, shown in greater detail in Fig. 518. This brake consists of a small leather pad M, fastened to a short arm which projects downwards from the nipping lever L, pivoted at Q to a sector-shaped lever behind, which carries two weights, W W, to increase its downward-bearing power. This weight-lever is loosely pivoted on the arbor, P, and turns solidly with the wheel when the brake is applied. There is a stop, S, to limit the descent, but it is in this case applied to the tail of the nipping lever. A connecting link, G, joins the nipping lever, L, to a see-saw lever AB which is pivoted at F. The internal position of the

brake appears to have two advantages, namely, long leverage around the fixed pin, making the feed more sensitive, and greater protection from dust and dirt. One peculiarity of the Brockie-Pell lamp is seen by reference to Fig. 517, namely the use of a see-saw lever

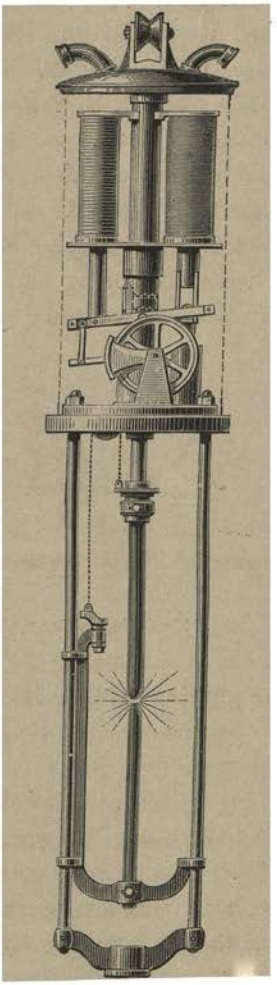

FIG. 517.—Brockie-Pell Lamp. External View.

above the clutch-wheel; this see-saw being worked by two iron plungers which are respectively attracted upwards into two hollow solenoïds or coils. One of these coils is of thick wire and is in the main circuit, the other is of fine wire and is connected as a shunt. The

series coil performs the operation of striking the arc. This it does by attracting the core attached above the end A of the see-saw lever. When this rises it causes the lever L to turn on its pivot Q, bringing the brake-piece M against the rim of the wheel. As the lever AB rises further it lifts the tail of the lever L off the stop S;

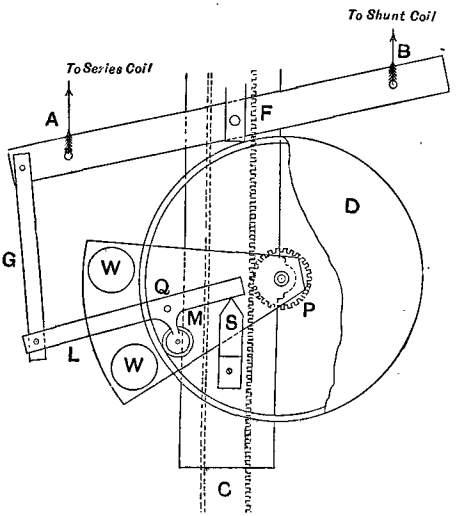

FIG. 518.—Brockie-Pell Lamp.

the wheel turning with the lever and raising the upper carbon. To feed the arc the lever L is lowered until the tail just presses against the stop S, thus relaxing the brake for a moment and permitting the wheel to turn through a small angle.

§ 3.—*Electric Candles.*

An electric candle is distinguished from other apparatus for producing a voltaic arc by the parallel arrangement of its carbons, which are not placed end to end on the same horizontal or vertical line, nor so as to form between them an angle more or less acute. In this very simple case, the arc forms between the carbon-points placed side by side, and no mechanism is needed.

A Russian officer, M. Jablochkoff, first devised this ingenious, economical, and practical solution of the problem of lighting by

electricity in 1876. The two carbons are two cylinders, or rods, separated by a cold insulating substance, which becomes a sensible conductor at the temperature of the voltaic arc; this substance was at first kaolin, which gives great regularity of light, but now, a mixture is used of equal parts of plaster of Paris and heavy spar (sulphate of calcium, and sulphate of barium), which does not melt like kaolin, but volatilises in the arc and increases the intensity of its light. For starting the light, the free ends of the carbons are united by a small layer of carbon *a* (Fig. 519), supported by a band of asbestos *a b* or, more simply, impregnated with a layer of a mixture of gum and plumbago. As soon as the current reaches the carbons, this layer becomes red-hot, quickly burns away and then the arc is formed.

The consumption of carbon, when the arc is fed by a continuous current machine, is much more rapid at the positive pole than at the negative, and Jablochkoff at first tried to remedy this great fault, which by bringing about a difference of level in the two points would quickly have extinguished the light. He made the positive carbon double the size of the negative one; but experience has shown that then the negative because of its greater resistance became red-hot too far down. Alternate current machines are therefore employed and thus the consumption of the two carbons remains always equal. Alliance, Lontin, Gramme, Siemens, and Wilde machines have been tried; but Gramme's self-exciting alternate current machine appears to give the best results. A machine of this kind with four circuits feeds twenty lamps, five lamps on each circuit. In the experiments made in London with Jablochkoff candles for lighting the Thames Embankment a candle has been kept alight at a distance of nine miles from the electric source. But this is an exceptional result; in reality and in ordinary practice, the most advantageous average distance is 160 yards; beyond that it seems preferable to fix a new generating centre, or to use transformers.

The Company which carries out Jablochkoff's system of lighting makes three kinds of candles. The first, the carbons of which are about one-fourth of an inch in diameter, gives a light equal to 570 standard candles, and requires one and a half horse power for each lamp. The lamp with carbon one-sixth of an inch in diameter gives 430 standard candles and absorbs one-horse power. The little lamp

with one-eighth inch carbons gives 240 to 285 standard candles and requires from four to five-horse power for a series of twelve lamps With a length of nine to ten inches, the duration of the light is from an hour and a half to two hours.

Figure 520 shows how Jablochkoff candles are arranged inside a

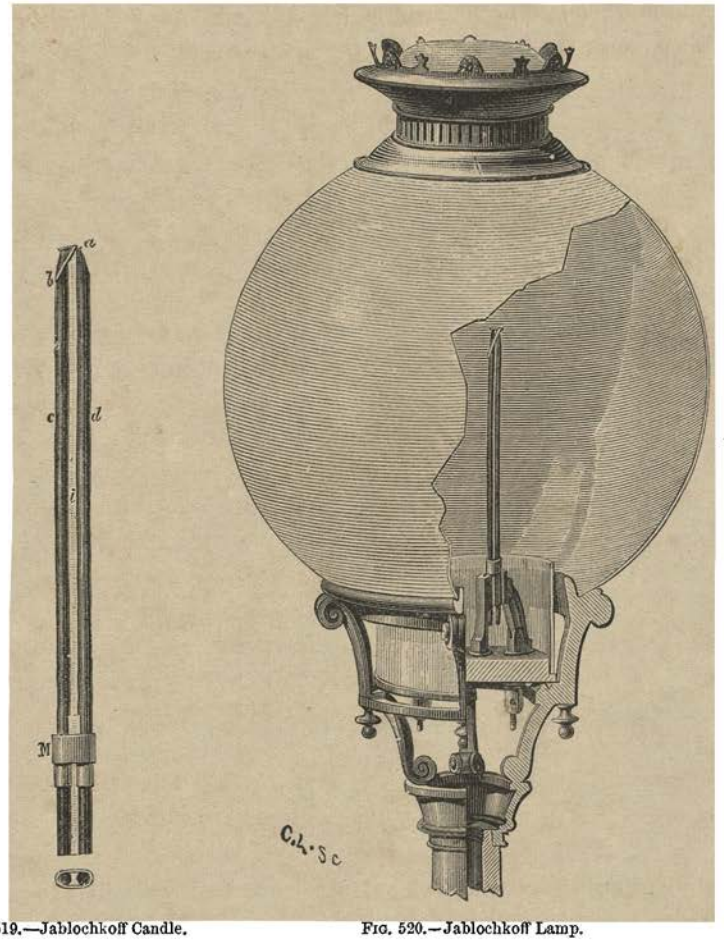

FIG. 519.—Jablochkoff Candle.

FIG. 520.—Jablochkoff Lamp.

semi-transparent globe. Four can be placed in each globe; they are fixed into clips with a spring, the two insulating branches of which are in communication with the conducting wires. At first the current is passed into one of the candles, and, when this is consumed, the current can be passed into a second, by means of a commutator

worked by hand, and so on. The light can thus be arranged to burn for a total of eight hours.

Wilde's lamp (Fig. 521) is constructed like Jablochkoff's with two parallel carbons, but differs firstly in the the carbons not being separated by an insulating substance and secondly in one of them being movable. The current is brought on one side to the fixed carbon, on the other side to the movable one and passes

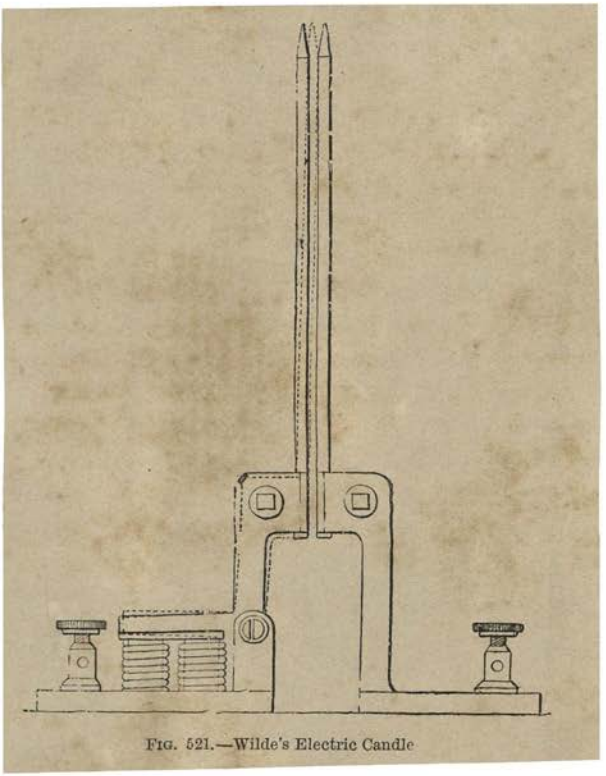

FIG. 521.—Wilde's Electric Candle

through an electromagnet situated in the base of the lamp with an armature which is attached to the movable carbon by a bent lever. Before the closing of the circuit the movable carbon rests against the other, as the dotted line in the figure shows; but when the circuit is closed, the armature is attracted and, by moving the lever, tilts the movable carbon to a position parallel to the other, and holds it there while the current lasts. The separation of the points "strikes" the arc, which is formed between them and which persists

till the carbons are consumed. Wilde's lamp must of course be fed by alternate currents which may be furnished by an Alliance or a Wilde's machine. When the arc is extinguished, the movable carbon returns to its original position, and the relighting is accomplished automatically and almost instantaneously.

Relying on the fact that the voltaic arc is nothing more than a portion of the current, subject like all currents to the laws of Ampère on the reciprocal actions of parallel elements, Jamin surrounded the carbons of the candles with a directing frame, formed of forty circuits of fine insulated copper wire. The alternate currents destined to feed the arc of the lamp pass into the wires of the frame, following a path parallel to that which they have in the neighbouring carbons. Then, if the contact of two carbons in any point whatever of their length by a third carbon forms the voltaic arc, this arc following Ampère's laws would be subject to the combined action of four sides of the directing frame, and would be repelled to the ends of the carbons, where it would remain. Therefore the candle can be placed in any position, without the arc ceasing, under the influence mentioned, to pass to the end of the carbons. In consequence of this arrangement the luminous point can be placed at the bottom, which avoids shadows, and besides, the insulator of Jablochkoff's lamps is no longer necessary.

The following is the description Jamin gives of the last form of his electric lamp: "It rests," he says, "on a base of slate B B B (Fig. 522) that can be fixed in globes or lanterns, as needed, and which supports a groove of copper H H H, wide but not thick, so as to avoid shadows; near the top is placed a ring of soft iron G destined to be magnetized, and to attract a movable plate E F. The alternate current of a Gramme machine passes at first into a fine copper wire doubled fifteen or twenty times in the grooves and constituting the directing circuit. The candles, or pairs of carbons between which the arc is formed, are placed in the middle of this frame and in its plane. There are usually three of them, but more can be employed if it is necessary to increase the duration of the light.

"Each of these carbons is placed in a tubular collar of copper where they are, by a spring, kept vertical with the points downwards. The operation of fixing the carbon is quite simple and requires no training; there is no insulating material between them. The carbons

on the right of each pair are fixed and vertical: those on the left hang freely from the joints B B′ B″; the tops of their supports are connected by a little bar C C′, which can move them simultaneously; the plate E F is attached by a lever E D to this bar, which it pushes to the left by its weight, thus moving the carbons till one of them strikes against the next one. It should be observed that contact

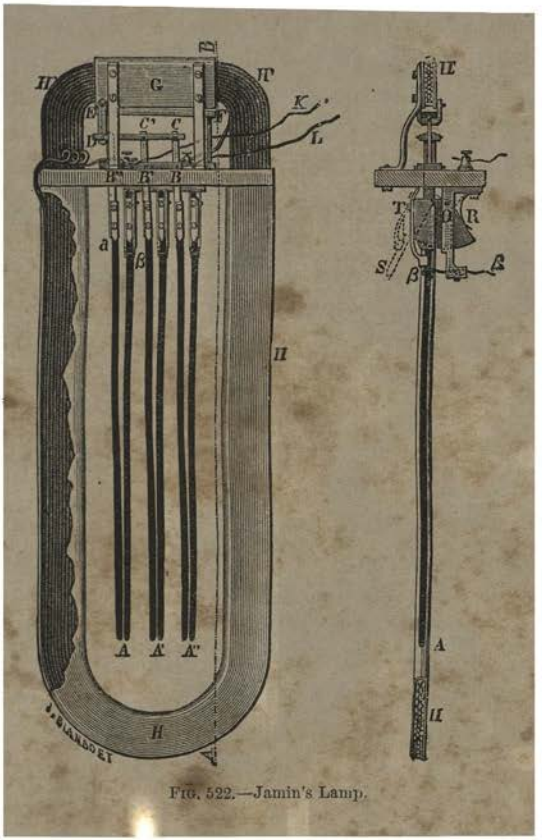

FIG. 522.—Jamin's Lamp.

takes place with only one pair of carbons—either the longest, or that in which the points are the nearest—and that it is this one which lights up. The electric current, having traversed the directing circuit, arrives at the same time at the three movable carbons, and can return by either of the three fixed ones; as a matter of fact it traverses only those which touch, and lights them. The iron sleeve is at once magnetized and the plate is attracted; the three pairs of

carbons are drawn apart, but two remain cold, and the arc is only struck between the carbons of the third pair. It remains at this pair as long as there is matter to burn, and is kept at the points by the action of the directing current, necessarily returning to them if any external cause momentarily separates it from them.

"When the current stops, the plate falls back, and contact is re-established; if it passes afresh, the carbons are again lighted, and separate as before. Thus the lighting is automatic, instantaneous and renewable at will."

Jamin shows then how, when the first candle is consumed, a second succeeds it, and by what means he obviates the possible or sudden extinction of one of the lamps in the circuit; he then sums up in the following terms the advantages of his electric lamp: "Our lamp combines many essential qualities: it can be lighted, and relighted as many times as desired; it only requires one circuit for all the lamps; it replaces automatically by new ones the carbons which are burnt up; it employs no insulating material of a nature to alter the colour of the flames, nor is any preliminary preparation which sensibly increases the expense of the carbons necessary."

With an eight-horse power motor, and Gramme's four-light machine, Jamin has been able to feed 24 lamps. "As for the light of each lamp," he says, "it diminishes with the number; with a speed of 1500 revolutions one lamp by itself gives 1270 candles; 2 give each 1070 candles, and when there are 14 they are not equal each of them to more than 475 candles." The distance to which the circuit can be run increases with the speed of rotation of the machine: at 1500 revolutions you may introduce 0·6 of a mile of copper wire of one twenty-fifth of an inch diameter into the circuit; at 2000 revolutions 2½ miles of the same wire, or 10 miles of wire of one-twelth of an inch diameter. Hence Jamin concludes that it is possible to light up the whole of a large town with one manufactory, with circuits radiating in every direction.

Jamin's lamp has been criticised as having the following defects: variations in the intensity of the light, proceeding from the lengthening and shortening of the arc, which lacks fixity; the absorption of power by the directing frame, and shadows projected by the same Wilde's and Jablochkoff's lamps have also the fault of being variable in intensity and in colour, but they are more simple and more economical.

§ 4.—*Semi-incandescent Lamps.*

Though the carbon pencils of the sun-lamp are not placed parallel like those of the Jablochkoff lamp, yet its light is, like the latter, due to the voltaic arc, which is however increased by the incandescence of an imperfect conductor; it requires, like the lamps just described, an alternate current machine.

The inventors, Messrs. Clerc and Bureau, give to their lamp the form shown in Fig. 523. The two carbons, of semicylindrical form, make an angle of about 40° with one another and slide by their own weight through openings made in a rectangular block, composed of a mixture of refractory materials (granite, white stone, and marble). Their extremities end inside a cavity, hollowed out under the block in the form of a roof: the crown of this cavity in the marble, or agglomerate magnesia, is traversed by the voltaic arc, which is produced by the passage of the current. (For striking the arc the two points of the carbons are united by a thin slip of carbon, which heats and consumes at once.) The arc when once struck remains constant, because the carbon-points are kept at a fixed distance apart by the refractory substance which the high temperature renders conducting and incandescent.

With the arrangement above described and figured, the light of the lamp is projected in a conical bunch of rays, very open from top to bottom. But the cavity can be made on one side of the block, if a lateral light is wanted, or the lamp can be reversed, if the light needs to be projected upwards—to light a ceiling, for example. In this case, springs are necessary to move the carbons. In a trial lighting up of the Opera with a sun-lamp, the movable carbons were replaced by two rather large blocks of carbon; as the combustion consumed the blocks, the length of the arc increased; but it was not extinguished for many hours.

The fixity of the luminous point, or the light itself, the slight yellow tint of which is agreeable to the eye and not fatiguing, and the simplicity proceeding from the absence of all mechanism, are the principal qualities which distinguish the sun-lamp. Like all apparatus working by means of alternate currents, it makes a

disagreeable humming noise; but this noise is imperceptible where the lamp is inclosed in lanterns perfectly closed. The consumption of the carbons is very slow; it varies from one third to two thirds of an inch per hour, and, as their length may reach ten inches, the duration of the light is about sixteen hours. According to experi-

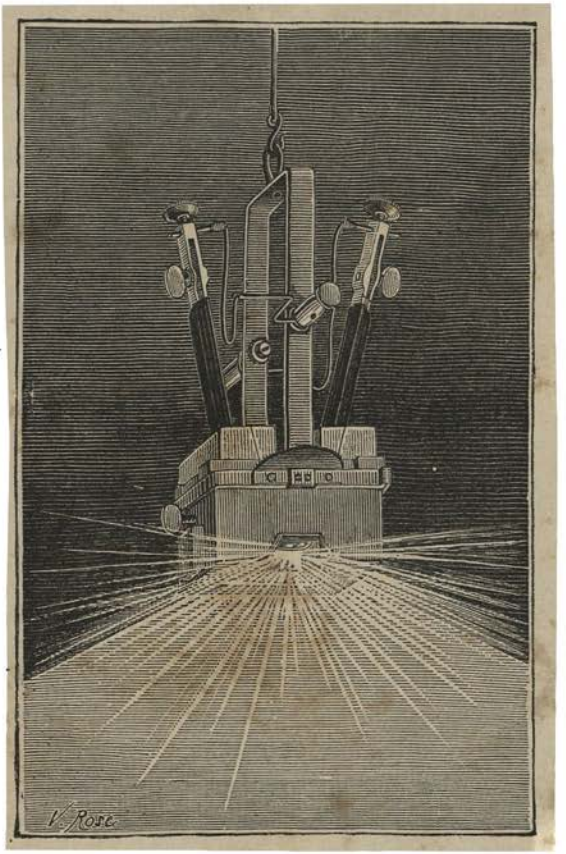

FIG 523.—The Sun Lamp.

ments made at Brussels in 1881, the luminous intensity in carcels of two lamps fed by a Gramme machine running at 2,000 revolutions was 5,500 candles; with twelve lamps in the circuit the maximum intensity reached 1,330 candles for each lamp.

Reynier designed a lamp in 1878, the principle of which is described by the inventor in the following terms:

"A cylindric or prismatic rod of carbon C is traversed from *i* to *j* (Fig. 524) by a continuous or alternating current large enough to render this portion incandescent. The current flows between the contacts *l* and B; the former, which is elastic, presses laterally against the carbon rod, whilst the contact B touches it at the end. Thus the carbon is worn at its extremity *j* quicker than at any other place, and tends to become shorter there. Consequently if the carbon rod C is pushed continually in the direction of the arrow so as to always touch the contact B, it will gradually advance as it wears, by slipping past the side contact *i*. The heat developed by the passage of the current in the rod is greatly increased by the combustion of the carbon. In practice the fixed contact is replaced by a revolving contact B, which carries off the ashes of the carbon. The

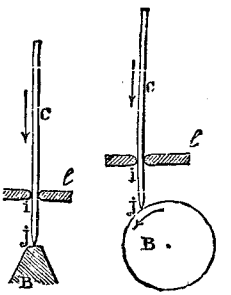

FIG. 524.—Principle of Reynier's Lamp.

rotation of the contact at the end is retarded by the forward movement of the carbon rod, so that its position on the contact at the end acts as a brake on the motive mechanism."

We will now show what arrangement Reynier has adopted for the construction of a lamp working according to this principle.

C C (Fig. 525) is a carbon rod 0·08 inch in diameter, supported by a rod A which is fastened into a hollow column D in which it can slide. One end of this rod rests on a cylinder R of carbon, movable round a horizontal axis supported by the column. At a distance of about a quarter of an inch from the point, the carbon stem passes through a contact furnished with a curb; by this contact the positive current enters the carbon rod, which it leaves by the carbon cylinder, and passing along the conductor on the outside of the

column, it reaches the negative terminal of the lamp. As the carbon rod burns up, it descends by the greater incandescence of its end, and its movement of descent causes a continuous rotation of the cylinder; for this purpose the direction of the stem does not pass

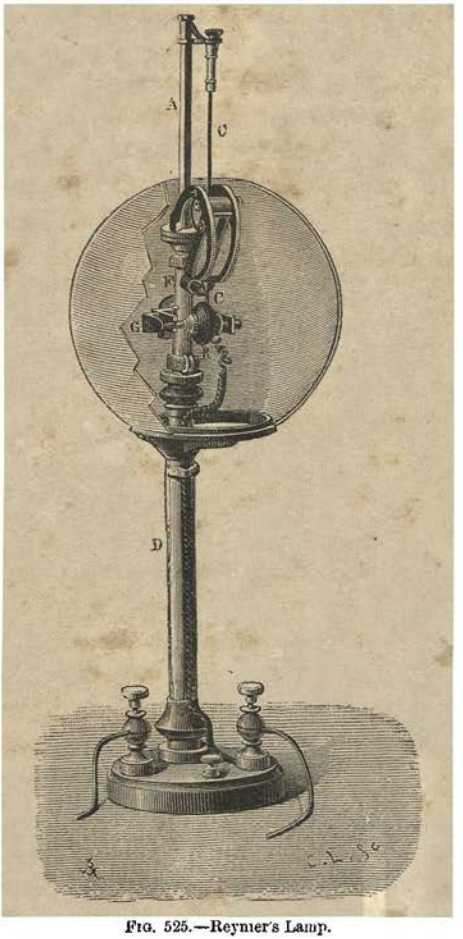

FIG. 525.—Reynier's Lamp.

through the axis of the cylinder, but a little eccentrically, as may be seen in figure 524. In this way, the ashes accumulated at the point of contact by the combustion of the carbon are removed.

Werdermann's lamp is very nearly the same as Reynier's lamp reversed. A carbon rod, movable inside a metal tube T which

guides it, and which is connected with the positive terminal of the lamp, is raised by the action of a weight P and presses against a thick disk of carbon C, which forms the negative pole of the arc. Only the very short portion of the rod between the disk and the tube that supports it is traversed by the current, it becomes incandescent, and its light is added to that of the very small voltaic arc, which forms between the two carbons. It is the great resistance which the imperfect contact of these oppose to the passage of the current that, in Werdermann's lamp as in Reynier's, causes the high

FIG. 526.—Werdermann's Lamp.

temperature, and the incandescence of the rod. Its point burns with great brilliancy, and the particles of carbon, which volatilize and radiate round it, constitute in reality a true voltaic arc. The lamps of this category are not purely incandescent lamps: they form a transition between these and arc lamps, properly so called; they are therefore usually referred to as "semi-incandescent lamps." We shall finish this chapter, already rather long but yet incomplete, on apparatus invented to apply the electric light to public use by a description of incandescent or glow lamps.

§ 4.—*Incandescent Electric Lamps.*

The first trials of lighting electrically by incandescence date from 1841; at that time an Englishman, De Moleyns, constructed a lamp the light of which was due to the incandescence of a platinum wire. This attempt was renewed by Starr and King in 1844, by Petrie in 1849 (the latter employed incandescent platinum), then in 1857 by De Changy, who tried also thin slips of bone charcoal inclosed in a vacuum in glass globes. The great radiating power of carbon, its much greater resistance than platinum, and above all its infusibility caused it to be substituted for platinum in the subsequent researches of inventors. Lodyguine, Konn, Bouliguine, and Sawyer, from 1873 to 1879, all constructed lamps founded on the incandescence of carbon, either in the air, or in a vacuum, or in a medium unsuitable for combustion, like nitrogen.

After repeated but fruitless trials of platinum, the employment of carbon was resumed, and different systems of incandescent lamps succeeded in surmounting the difficulties which had proved insuperable to the first inventors. We shall successively describe four lamps that worked with success at the Paris Exhibition of Electricity in 1881. They are all however very similar.

In Edison's lamps (Fig. 527), the carbon, bent like a letter U, is a filament made of bamboo fibres, carbonized by a special method. In spite of its extreme fineness, this filament has great rigidity; its ends, which are thicker, are passed into platinum clips, and these are joined to the conducting wires, also of platinum. The whole is sealed in a glass receiver of an oblong form, from which the air is removed, with a mercury pump. When the vacuum is nearly perfect, the carbon is raised to incandescence, so that the last bubbles of gas lodged in the pores of the filament are expelled, and it becomes very hard and dense. The carbon can now be caused to glow without combustion taking place, and the separation of carbonized particles produced in the early trials, and which caused them to fail, is very much diminished. Edison constructed two varieties of these lamps, which were designed to burn with intensities of sixteen and eight candles respectively.

The carbon disintegrates in process of time, but it is said that

the life of the lamp is 1,200 actual working hours. We shall presently describe the great dynamo machine due to him also, and which is capable of lighting 2,400 lamps of the smaller size, on the same circuit.

The carbon filament for the incandescent lamp designed by Lane-Fox, Fig. 528, is formed of fibres of French whisk carbonized; its ends are placed in two little cylinders of plumbago, which also receive the platinum conducting wires of the circuit. As in Edison's system,

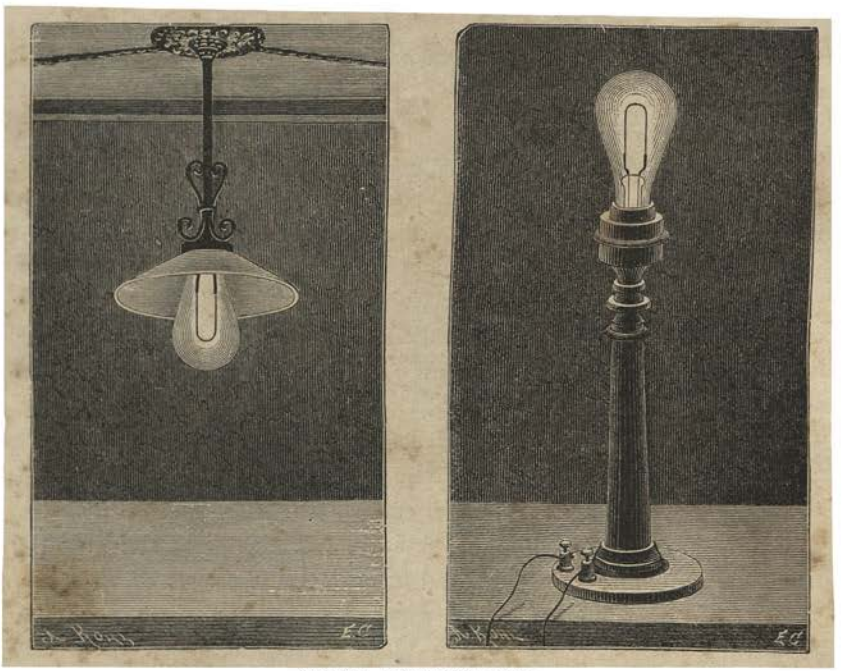

FIG. 527.—Edison Glow Lamp.

the carbon is brought to incandescence during the exhaustion of the glass receiver by the mercury pump. It is asserted that with a two-horse power engine fifteen Lane-Fox lamps can be fed, each of which would have an intensity of twelve candles.

In Maxim's lamps (Fig. 529) the carbon is in the form of the letter M, cut from bristol board, and carbonized between two plates of iron heated to a certain temperature. After the air is removed from the glass receiver, the vapour of a hydrocarbon (gazoline) is introduced;

and the current is passed through the carbon. There then forms, on the surface of the filament of carbon, a deposit of carbonized particles of the gazoline, which renders it more tenacious and stronger. The form of the carbon and its thickness, which is greater than in the other incandescent lamps, contribute to give a higher intensity of light in Maxim's lamps. With one-horse power the inventor says he can feed six lamps, each of twenty-five candle power.

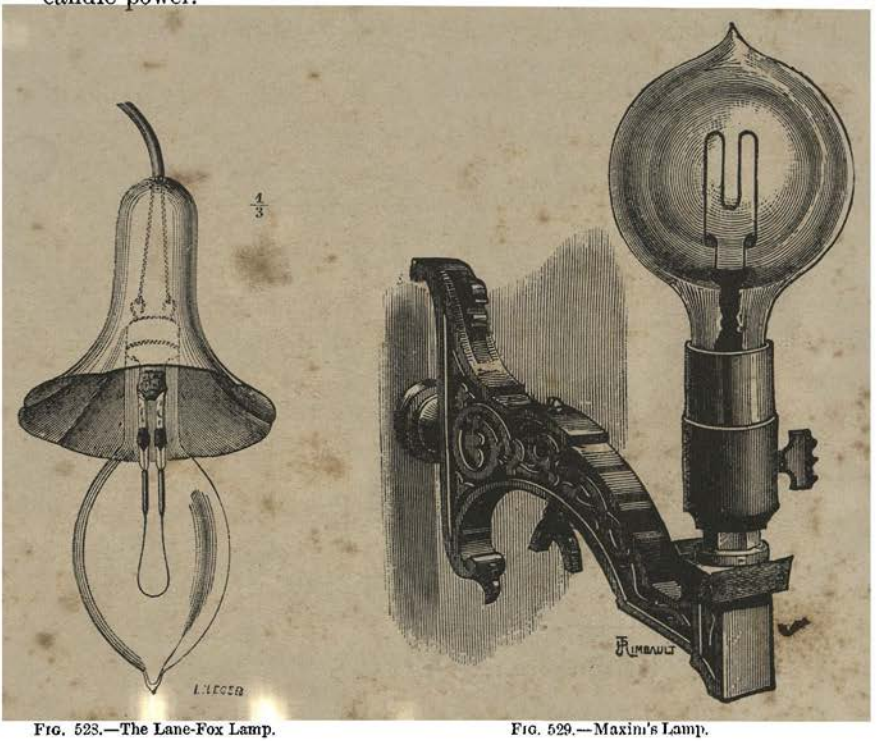

FIG. 523.—The Lane-Fox Lamp.

FIG. 529.—Maxim's Lamp.

The last variety of incandescent electric lamps that we shall describe is that invented by Swan, who, at the time when Edison was still attempting to produce a platinum lamp, had constructed, and was publicly exhibiting a carbon lamp. In this early form the filament consisted of a straight carbon wire one millimetre thick, and about one inch long, mounted within an exhausted globe of glass through which the leading wires of platinum were fused. The arrangement of his modern lamps, as seen in Fig. 530, is very

like those already described. The carbon is made of threads of cotton, about four inches long, which have been hardened by soaking in sulphuric acid. Its form is that of a letter U with a curl at the end, in order to concentrate more light at that place. The extremities of the carbon are thicker, and are fixed into platinum contacts passed through the bottom of the receiver, and attached to the conductors. Whilst the air is being exhausted the current is passed as we have already described; this process, which is known as running on the pumps, is due originally to Swan. The Swan lamps of sixteen

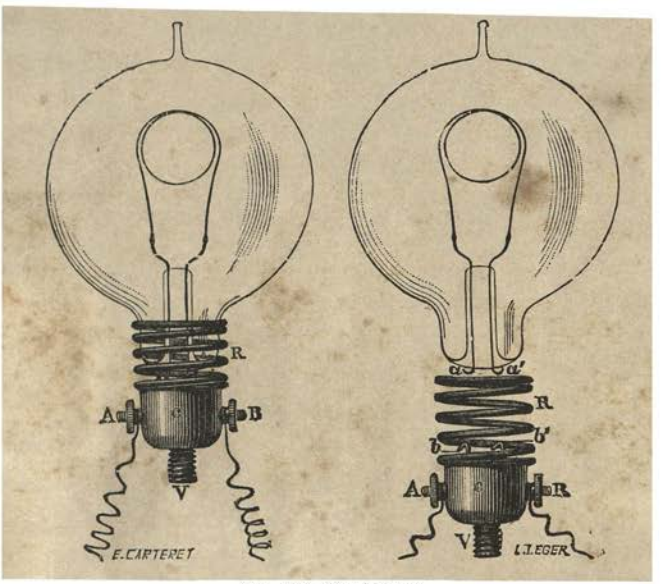

FIG. 530.—Swan Lamp.

candle-power require a current of about six tenths of one ampere, when supplied at a pressure of 100 volts; from ten to twelve such lamps can be fed with one horse-power. Of the above lamps the Swan and the Edison are the ones now most largely used, owing to various decisions of the law courts on the conflicting patent rights.

Now that we have described the most important of the systems of lighting by electricity, it remains for us to complete our descriptions of the generators which feed them, and to describe some machines which have been specially arranged for the production and distribution of light.

§ 5.—*Dynamo Machines for Lighting.*

The generators of electricity which we described in Chapter X. of the first part of this volume are susceptible of many different applications; but the great progress realized, in these latter years, in lighting apparatus has led the constructors of magneto- or dynamo-electric machines to researches which have had for their object special application for the production of light. They have tried to improve the light, and then to solve two special questions, essentially connected with the practical solution of public or private lighting with electricity. One of these questions is that of the division of light, that is, of a combination which allows of feeding with the same machine, on the same circuit or on many parallel circuits, the greatest possible number of lamps. In certain cases, without doubt, it is necessary to produce the most intense light possible, and by the aid of projectors to concentrate the light on a contracted space. But what is an advantage in such a case, is on the contrary an obstacle if public lighting is required, either exterior or interior: then the division of the light of the arc into a great number of lamps, which diffuse it over various areas, is an essential condition of success.

On the other hand, the invention of electric lamps and other similar apparatus, which require the employment of alternate currents, has caused the modification of existing machines invented for the production of continuous currents.

The solution of the second question was more simple as regards the magneto-electric machines. We have seen that these machines naturally give at each turn two currents in opposite directions, and that, to change this and to obtain continuous currents, they are furnished with a commutator. The great machines however, of Nollet and Malderen, or the Alliance, as well as that of De Méritens employed in lighthouses, are alternate current machines. The solution is not so easy with dynamo-electric machines, where the continuous current of the machine is used for magnetizing the field-magnets. With alternate current machines, on the other hand, it is necessary to employ two machines; one called the Exciter, because it serves with its continuous current to animate or excite the electro-magnets of the

second—this latter being the machine used to furnish the alternating currents necessary for feeding the lamps.

To Wilde, of Manchester, belongs the honour of having first given the solution of this double problem. He was followed by others, notably in 1877 by Lontin of Paris. We have already described the machine he employs as an exciter to his larger machine. It remains for us to speak of the latter.

The two portions, the field-magnet and the armature, which compose it, are formed on two concentric cylinders, one of which, the exterior one, is fixed, and the other the interior one, which constitutes the field-magnet, is movable. This latter is formed of a series of coils, A, the spindles of which are fixed in the direction of the radii of the cylinder. The coils of these magnets, of which there are twenty-four, are wound in a direction contrary to each other, so that under the influence of the current of the exciter, which is introduced at the two terminals F F (Fig. 531), the polarities of two consecutive coils are alternate.

The cylinder, or the crown forming the armature, has also twenty-four magnet coils, B, joined two and two, so as to form twelve complete electro-magnetic systems. When the field-magnet rotates, the magnetic poles of the field-magnet bobbins pass successively without touching them, before the poles of the armature bobbins. The result is that alternate currents are induced in these bobbins the directions of which, at each revolution, change twenty-four times. The ends of the coils are joined to fixed terminals on the sides of the machines at M and N, and from there are sent into the lamps on the circuit. With this arrangement Lontin's machine can feed twelve separate lamps. But, by the aid of a commutator, with little handles placed at M and contact plates, the currents of the armature coils can be connected at will, so as to establish twenty-four separate circuits, that is to distribute the current from the various groups of coils to separate circuits, in any desired strength that may be required.

This machine, Du Moncel says, has been applied to lighting the wet dock of the railway at Lyons, where it supplies current to thirty-one lamps. These lamps are worked from one electric generator, and two armature systems of twenty-four coils each. By coupling these coils together and interposing on each of their circuits several Lontin electric arc lamps, they have been able, by a convenient combination of these

coils with regard to the length of the exterior circuit, to work thirty-one lamps, each of which was about equivalent to 380 standard candles. These machines are also used at the St. Lazare dock at Paris. They feed there twelve lamps, two of which are placed at 750 yards from the generator.

Figure 532 represents Gramme's alternate current machine, the armature of which is fixed, and the field-magnet is excited by a Gramme generator, like that which we have already described and represented under the name of "workshop type" in Figure 277.

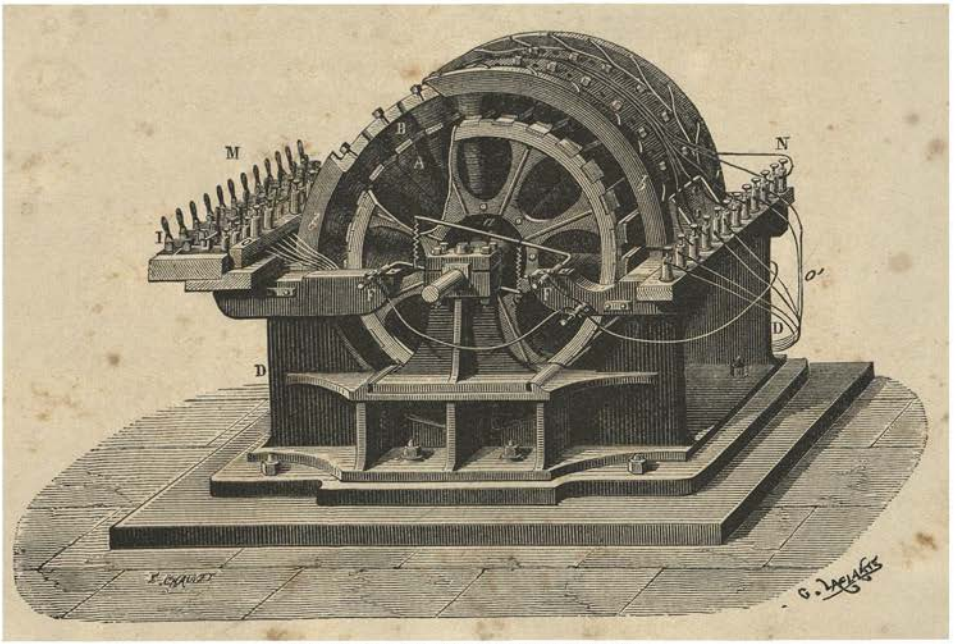

FIG. 531.—Lontin's Alternate Current Dynamo.

The field-magnet is carried on a steel axle which bears eight electromagnets B ranged round an octagonal hub on the axle. The coils of these electromagnets receive by means of two silver copper wire brushes the current of the exerting machine. The eight poles of the field-magnet are alternate, so that a north pole succeeds a south pole, and they have their pole-pieces distinct, leaving a small interval between them. The armature is composed of thirty-two exterior bobbins, wound on a soft iron ring or on a series of circular

segments of soft iron arranged end to end. The copper coils can be coupled at will into twos, fours, or eights, so as to obtain sixteen, eight, or four distinct currents, or they can remain independent and will then give thirty-two currents. By its rotation, the field-magnet develops in the coils of the armature alternate currents in opposite directions. This machine began to work in January 1878, feeding the electric lamps near the Opera at Paris.[1]

Hefner-Alteneck's alternate current machine, constructed by

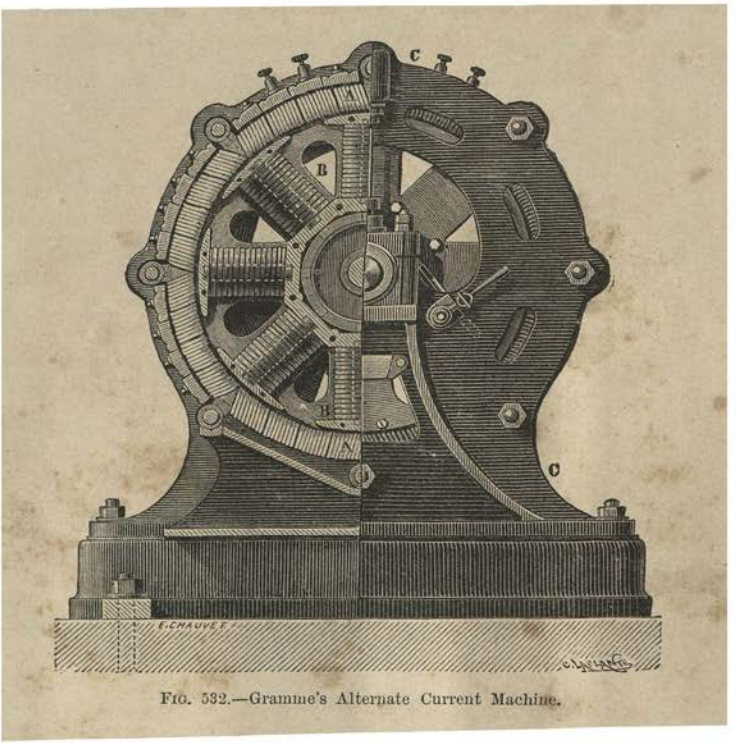

FIG. 532.—Gramme's Alternate Current Machine.

Messrs. Siemens and Halske, differs from Lontin's and Gramme's by having the field-magnets fixed and the armature movable. The system of field-magnets is double, and it is in the annular space which separates the two parts that the armature turns. And the coils of the latter do not inclose an iron core so that the current is

[1] Comparing Gramme's machine with other similar alternate current machines, Fontaine remarks that their fundamental difference consists in the reciprocal position of the bobbins, and the electromagnets.

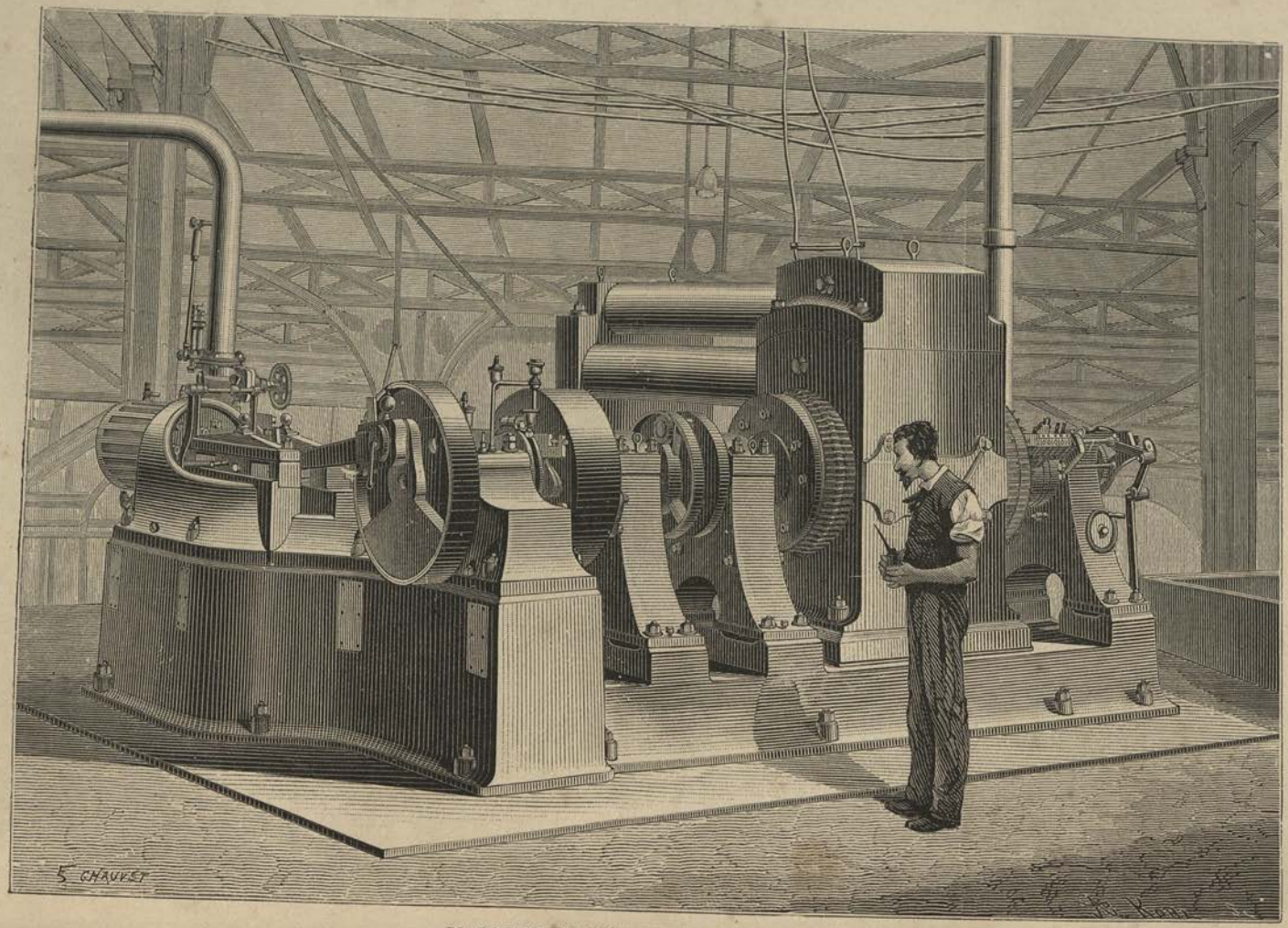

PLATE XIII.—EDISON'S STEAM DYNAMO.

only developed by these coils cutting the magnetic field set up by the field-magnets. A machine of this kind with sixteen coils can feed, in two circuits, 20 Siemens' differential lamps.

There were at the Exhibition of Electricity in 1881 a great many machines having for their principal object the production of light, almost as many as there were systems of electric lamps. But among about fifty generators, very few were distinguished by true originality. As we have described the principal ones, we shall now only mention the machines of Weston, Bürgin, Crompton, and Maxim, and give some details of one designed by the American inventor, Thomas A. Edison.

Before designing, and constructing a special machine himself for incandescent lamps, Edison had thought of employing a generator invented in 1875 by Farmer of Boston, and improved by another American constructor, Wallace.

The Wallace-Farmer machine, which is now obsolete, was formed of two similar parts, which could work separately. The armature was an iron disk bearing on both sides crowns of straight electromagnets, having the form of two flattened bobbins attached in series and the wires of which are connected with a Gramme commutator on the axle of rotation. This system revolved between two large electromagnets with flattened pole pieces, having contrary poles, opposing each other, which form the field-magnets of the machine.

Plate XIII. gives a full view of Edison's large machine. On the left is the steam engine of 125-horse power, which acts directly on the rotating axis of the generating machine, and which rests on the same frame. The field-magnet is formed of eight large electromagnets, arranged horizontally, three underneath and five above the armature. Two enormous masses of iron between which the armature turns form the poles of the electromagnets. As for the wires with which the spindles of the field-magnets are wound, they are relatively fine, and connected directly with the poles of the machine. The original part of the machine is the way in which the armature is arranged. Instead of wires wound as in a Siemens' bobbin, parallel to the axis of the cylinder, they are bars of copper which are joined together, two and two, by an equal number of annular and thin disks of copper, placed at the two ends of the cylinder and insulated by plates of mica. Each disk has two projecting lugs, nearly diametrically opposite, each of which receives one of the copper bars needed to

be joined together. The spindle of the bobbin which bears in its centre the driving-shaft has a wooden hub round this shaft supporting disks of iron separated by paper shields; so that the magnetic mass is supported and is more easily magnetized and demagnetized. The armature has 138 bars of copper, the extremities of which form, round the drum, a spiral curve, proceeding from the junction just described.

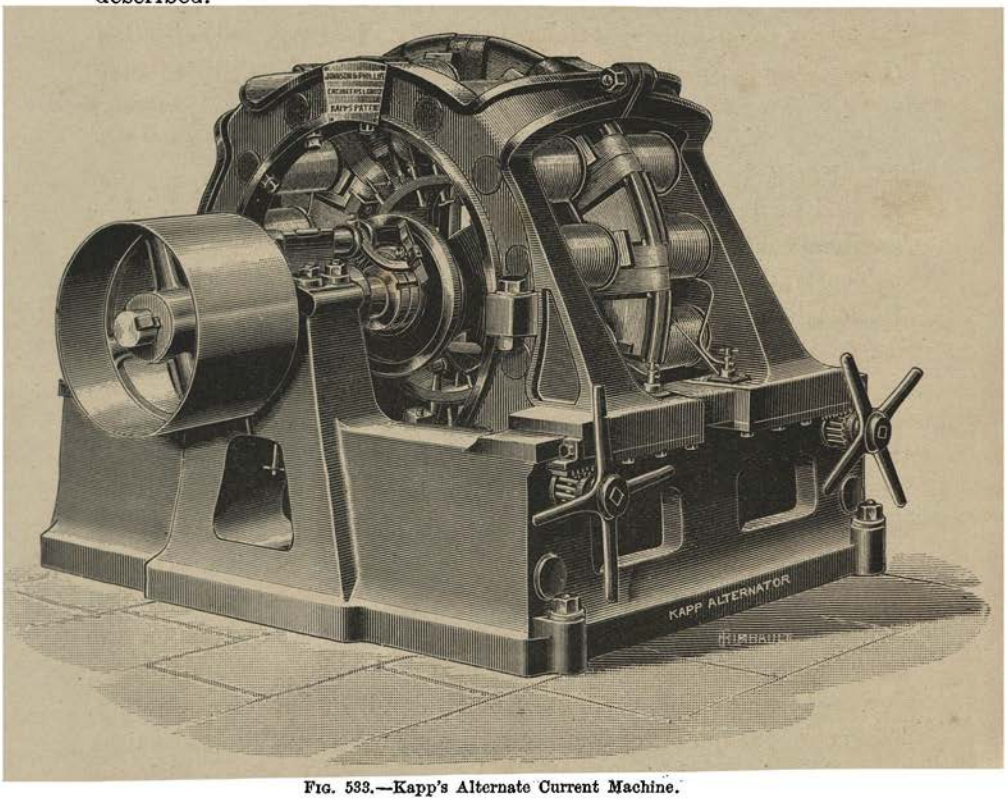

FIG. 533.—Kapp's Alternate Current Machine.

This gigantic machine was constructed to feed 2400 lamps of the smaller Edison or eight-candle power type, or 1200 lamps of sixteen-candle power. It was a type of one of the twelve generators which were constructed to serve for the electric lighting of a whole quarter of New York, on a system of distributing mains devised by the inventor. They have since been superseded by machines of more compact design.

Some of the more modern machines have already been described and figured in the previous part of the book (see Figs. 279 and 280).

One of the newest is the alternate current machine (Fig. 533) designed by Mr. Gisbert Kapp, and constructed by Messrs. Johnson and Phillips, of London. The field-magnets of this machine consist of two crowns of sixteen poles of alternate polarity set facing one another, so that opposite to each north pole is another north, and opposite to each south pole another south. Between them revolves, as armature, a ring built of iron hoops, well insulated and mechanically supported, over which are wound sixteen sets of copper wire coils, in which, as they revolve, electromotive forces of rapidly alternating sign are excited.

Another recent alternating-current dynamo is the Mordey alternator, constructed by the Brush Electric Engineering Company. In this machine, which is of great simplicity and solidity, the armature is stationary, and the field-magnet, a single coil with multiple polar projections, revolves.

CHAPTER XIII.

LIGHTING BY ELECTRICITY.

§ 1.—*Electric Light in Lighthouses.*

THE numerous lamps and generators together with other apparatus invented during the last forty years, but which have been so extraordinarily multiplied in these latter times, indicate the progress that electric lighting has made. We must therefore refer to the most important of its applications, and we will begin by that which has for its object the lighting of the coasts, or the illumination of lighthouses.

In works on optics it is shown how the invention of lenses has helped to carry to a high degree of perfection various systems for the protection of dangerous coasts. Thanks to Fresnel's admirable lenticular apparatus oil or gas lights of the first order have, in ordinary weather, sufficient power for coast service; but these lights fail when the atmosphere is foggy and when it would be most useful and necessary for sailors to be sure of their way. To increase the number of wicks of the carcel lamps employed is not a solution of the difficulty, for the power of the light depends not only on its apparent diameter, but on its intrinsic brilliancy. The employment of the electric light, the intensity of which is considerable, was naturally suggested, but the application of it was not possible until a convenient regulating apparatus and machines producing a sufficient quantity of light were invented.

Arc lamps such as those of Foucault and Serrin satisfied the first condition; and the magneto-electric machines of Nollet and others, which we have described, fulfilled the second. The first occasion when electric light was used for illuminating lighthouses was on the 8th of

December 1858, when the High Light at the South Foreland was lit by electric currents generated in one of Holmes's magneto-electric machines. It was not until 1863 that the electric light was applied to the lighthouses of La Hève. Since then it has been also used at Cape Grisnez and at Planier. England has for many years possessed six electric lighthouses, one at Dungeness, another at Souter Point, two at the South Foreland, and two at the Lizard. The two last are fed by Siemens' dynamo-electric machines, the others by Holmes's magneto-electric machines. More recently a still more powerful light has been erected at St. Catherine's Point near Ventnor in the Isle of Wight, the machine being of De Méritens's pattern. In the rest of the world there are now a number of electric lighthouses, one at Odessa, another at Port Said, and two others at White Rock and the Border Flats, United States. Also a new and very powerful light-house in the harbour of New York.

The most powerful electric lighthouses in the world are those of Macquarie near Sydney, Australia, and of Tino, a small island near the mouth of the Gulf of Spezzia. In both of these the dynamo machines are alternate current machines with permanent magnets of the De Méritens type. The lamps used are of the Serrin type. All the optical arrangements were manufactured by Messrs. Chance of Birmingham under the directions of Dr. John Hopkinson, who has given an account of these lighthouses in the *Proceedings of the Institution of Civil Engineers* for 1886.

The memoir on electric lighting of lighthouses by Allard shows that this interesting application is about to receive fresh extensions in France.

The magneto-electric machines of the two lighthouses at La Hève are driven by two locomotive steam-engines, of eight to ten-horse power. The maximum intensity of the light is obtained with a speed of 400 revolutions per minute. The light sent out horizontally from the lenticular apparatus and produced by a machine with four disks is equal to 33,250 standard candles, with a machine of six disks the effect of 475,000 candles is obtained, and the light is seen at the distance of 27 nautical miles, or 50 kilometres. This powerful source of light is the result of the combination of the induced currents, from the action of the forty-eight magnets on the ninety-six coils revolving in each machine.

Four such machines are placed in the lighthouses at La Hève. All the apparatus is double, in order that the immediate substitution of one lamp for another may leave no discontinuity in the light. The lamps are fixed on the rails of little tramways (Fig. 534), which meet at the centres of two sets of lenticular apparatus, fixed one above the other in the same lantern. The arc lamps employed are those of Serrin.

Not only does the electric light furnished by the Alliance

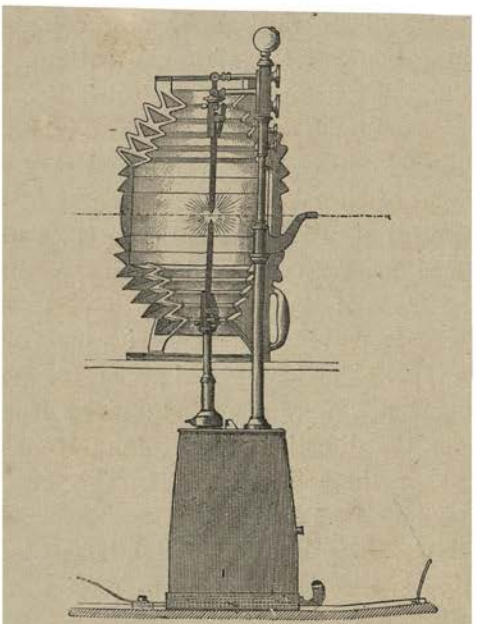

FIG. 534.—Electric Light Apparatus at Hève.

machines constructed by Malderen surpass in intensity those of the oil lighting apparatus by 5 to 1, but it is also more economical. Whilst a lighthouse where oil is used costs about three shillings an hour, an electric light such as that at La Hève costs only two and fourpence an hour using a machine with four disks; with equal intensity the price is a seventh less. In business the cost would certainly be less, provided that the light was employed ten hours a day. Where the motive power could be borrowed from powerful machines working for other purposes, as in many workshops, the electric light, as Le

Roux remarked, would scarcely cost more than the interest on the price of the magneto-electric machine and the lamps.

Interesting comparative experiments were made some time since at the Lighthouse Depot, between the magneto-electric machines con-

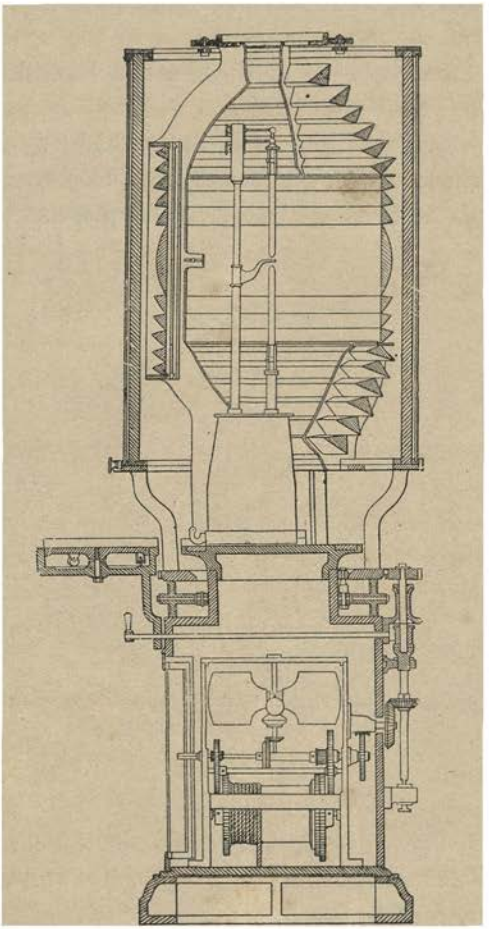

FIG. 535.—Planier's Electric Lantern for Lighthouses.

structed by Van Malderen, the machine of De Méritens, which we described in a preceding chapter, and three dynamo-electric machines of Gramme.

The conclusion drawn from these experiments was that "Gramme's machines give more intensity of light than those of the Alliance for

the same amount of power. The later machines of this system are a decided improvement on the old ones, since their out-put is increased more than one-half, but at the same time they require an increase of power. Gramme's machines give for the same amount of power 40 or 45 per cent. more light. In spite of the incontestable assurances that the machines of the Alliance present as to the security and continuity of the service, it is impossible not to recognize the greater power which the other system presents, and we have necessarily been led to make a practical trial of it in lighthouses." De Méritens's machine is constructed to give about the same power as Gramme's, but relatively it is more costly, though it presents the feature of

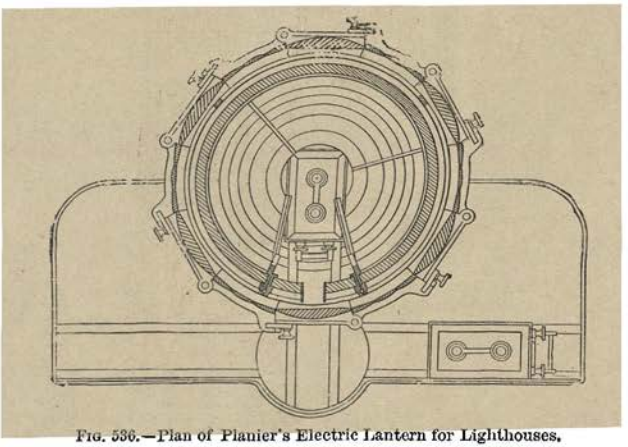

FIG. 536.—Plan of Planier's Electric Lantern for Lighthouses.

working with alternate currents, which permits the use of Serrin lamps of the type adopted in lighthouses.

The electric light is particularly favourable for flashing lights in groups of brilliant white or red, more especially white, the intensity of which is very considerable.

In calculating the total intensity of the lights projected to the horizon by the apparatus with a fixed light, we find that they equal 114,000 candles for the Alliance machines, 190,000 for Gramme's machines of the C type. In the revolving lanterns, which emit a brilliant red, the intensity in the axis is five times that of the fixed light; it reaches seven and a half times this value in those which give a brilliant white.

Taking as the intensity of this light, says Allard, the values we have just mentioned, we find the following intensities in round numbers :

	Alliance machine.	Gramme's machine, No. 2.
Flashing light brilliant white and red . .	570,000 candles	950,000 candles
Flashing light in groups of brilliant white	855,000 „	1,420,000 „

The opinion of the Lighthouse Commission in France is, that it is possible to transform forty-two of the existing lights into electric lighthouses, which would necessitate a total expense of about £280,000 sterling. By adding another £40,000 to this, they could complete the system of the protection of their coasts by the addition of twenty fog horns, or steam sirens.

The following tables taken from Allard's memoir give some numerical information concerning the luminous intensity of different machines, and the cost of electric light as compared with lighting by mineral oil:

POWER ABSORBED BY VARIOUS MACHINES, AND CANDLE-POWER OBTAINED PER HORSE-POWER.

		Horse-power absorbed.	Total candle-power.	Candles per horse-power.
Alliance machine. . . .		4·62	2,610 candles	565 candles
Grammes	No. 1 . . .	11·48	9,590 „	836 „
	No. 2 . . .	5·45	4,680 „	860 „
	No. 3 . . .	4·20	3,250 „	773 „

PRICE OF THE LIGHT PER CANDLE-POWER IN LIGHTHOUSES LIGHTED BY ELECTRICITY AND BY OIL IN ENGLAND AND FRANCE.

				£	s.	d.
French Lighthouses	Mineral Oil			1	15	7
	Electric	At Gris Nez (old machines)			9	7
		At La Hève (old machines)			8	6
		At Gris Nez (new machines)	Alliance		6	8
			Gramme		4	3
		At La Hève (new machines)	Alliance		5	10
			Gramme		3	9
English Lighthouses	Mineral Oil			2	5	10
	Electric	At Dungeness		2	10	5
		At Souter Point		1	5	8
		At South Foreland			19	4
		At Cape Lizard			6	4

This table shows the advantage of electric light employed for lighting lighthouses, from an economic point of view.

§ 2.—*Electric Light in Workshops.*

One of the first applications of the electric light produced by the voltaic arc, was to light up large workshops, whenever it was necessary to press forward the completion of contracts, and thus to add the light of night to the light of day.

The first attempt of this kind, at least that we know of, dates from the reconstruction of the bridge of Notre Dame at Paris: since

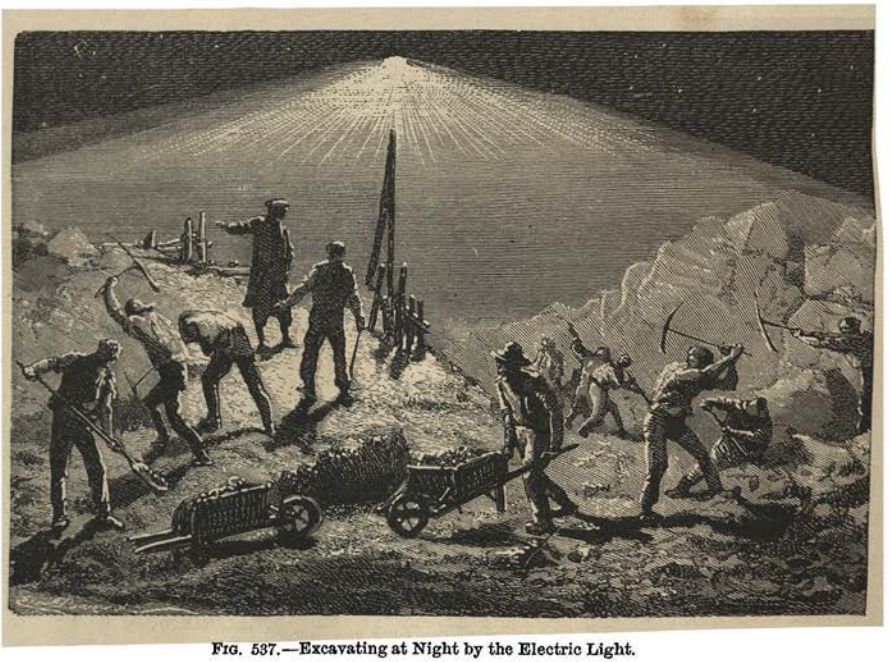

FIG. 537.—Excavating at Night by the Electric Light.

then the electric light has been used during the construction of Docks, for the building of the new Louvre, for the bridge of Kehl, &c. But for many years past this application has become so frequent in France and elsewhere, that it would be tedious even to enumerate works of this kind. We will only say that it is to the electric light that we owe the rapid erection of the Palace of the Trocadéro for the 1878 Exhibition, of the Chamber of the Senate at

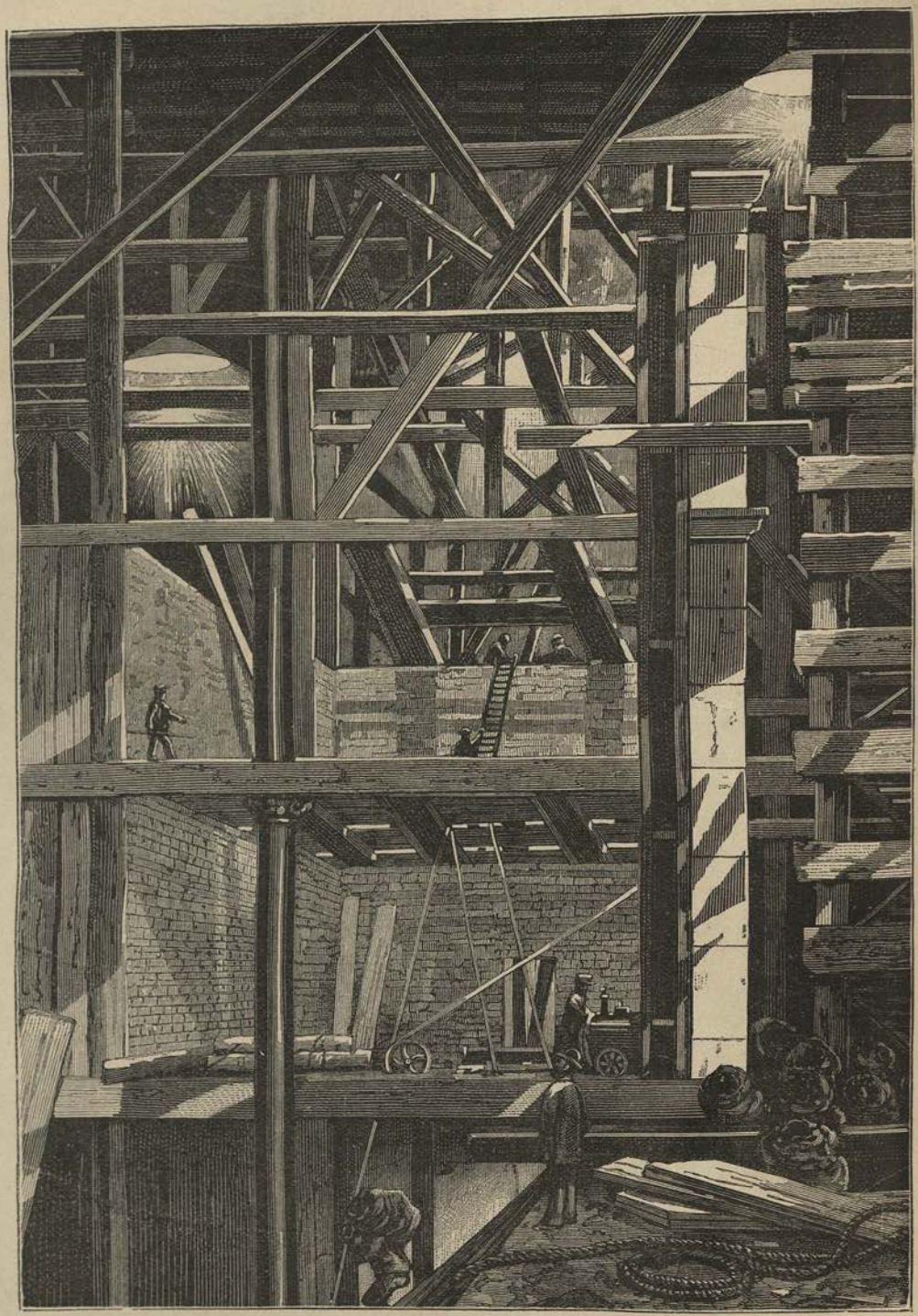

PLATE XIV.—THE ELECTRIC LIGHT USED FOR NIGHT WORK.
Building of the Magazin du Printemps, Paris.

the Luxembourg, and the prompt reconstruction of the Bridge des Invalides.

We shall content ourselves with mentioning, among the recent applications, that illustrated in Plate XIV. and the object of which is the reconstruction of the great Magazin du Printemps, situated at the corner of the Boulevard Haussmann, and the Rue du Havre at Paris, which was destroyed by fire in 1881. The apparatus employed to light up the works consisted of Jablochkoff candles and a Gramme self-exciting dynamo, driven by a portable engine of six-horse power, which was sufficient to feed eight lamps fixed in convenient parts amongst the scaffolding. Those seen in the figure are naked lights and are furnished with reflectors, but four others were provided with opal globes. As a remarkable application of electric lighting in public works, we may mention what has been done to extend the outer port at Havre.

For the execution of masonry and putting in piles, &c., below the water level, works which are not possible except at low tide, it was important to use the low water which occurred at night as well as that which happened in the daytime.

The director of the enterprise, Chéron, installed for this purpose two Gramme machines. The following, according to Fontaine, from whom we borrow the details, is how this remarkable arrangement worked:

"Visiting in detail," he says, "the works in course of execution, on a dark night with no stars, we observed that the men, placed at distances varying from twenty to one hundred and twenty yards from the lamps, could proceed with all the ordinary work without the least inconvenience. The miners perforated the old wall at one hundred and twenty-four yards from the nearest lamp, and executed the same amount of work as during the day. A locomotive, drawing ten waggons circulated on a road 1600 yards long, bringing materials for the work, and carrying away the clearings to the places marked out. One man drove in the piles by the aid of a steam-pile driver made for the purpose. Masons, carpenters, terrace-makers, &c., executed here and there works of every kind. More than 150 workmen, on a space of about 30,000 square yards, worked without any other light than that produced by the two Gramme machines. The light, placed in lanterns sixteen feet high, on level ground, were in reality forty-eight feet above most of the

positions of work. At one hundred and twenty-four yards, we read distinctly a newspaper, better than we should have done lighted by a gas jet placed at a distance of sixteen feet. Each lamp gave a light of more than 4,750 standard candles."

After the electric lighting of large workshops came that of railway stations and markets. We have already had occasion to say that this mode of lighting had been adopted by the Paris,-Lyons-and-Mediterranean and the Western Railway Companies of France. Five years ago the goods station of the Northern Railway Company at La Chapelle was similarly lighted. Four lamps suffice to light up a market 1,900 yards long, a store-house 1,140 yards long, and a court sixty-five feet wide, which separates them. The result is excellent: the receipt of packages, small and great, the writing which it necessitates, the distribution, and the lading, all are executed with so much facility and celerity, that an economy of 25 per cent. is considered to be realized by the adoption of this light. The expense is $7\frac{1}{2}d.$ per lamp per hour.

Installations of this kind are multiplying everywhere both in France and abroad. It is the same with the lighting of manufactories, workshops, and warehouses. Many spinning mills, weaving factories, dye works, machine shops, printing offices, &c., have substituted electric lamps for gas light. The problem to solve was not quite the same in many cases as for the great yards and markets, where brilliancy and abundance of light was all that was necessary. In these latter cases plenty of light, and at the same time as complete diffusion as possible must be obtained. For delicate works, a single and too brilliant light, besides fatiguing the eyes, has the inconvenience of producing the opposite of light, namely inconvenient shadows.[1]

[1] In describing the mode of lighting the workshops of Sautter, Lemonnier and Co., the well-known manufacturers of lenticular apparatus for lighthouses, shops whose superficial area is 2,100 square yards, and which are lighted with lamps each of 1,420 candle-power, fed by three Gramme machines, Fontaine adds:—"It can be imagined that in a workshop of this sort the shadows cast by the tools, by the *shafting*, or by the columns, are a great trouble and hindrance to the work, and that wherever the light does not directly shine, the contrast makes the obscurity greater than with any other mode of lighting. But with this light it is not so. The light diffused or, in other words, the light reflected by all the bright points is such that there is literally not any dark corner in the place, and a workman can easily distinguish objects placed at the bottom of his drawer."

But the invention of apparatus for distributing the light while allowing the multiplication of lamps fed by the same machine has caused the faults of single and too powerful lamps to disappear in a great measure. One of the great advantages of electric light compared with that of gas is the almost complete suppression of the heat disengaged by the old burners and the vitiation of the air by combustion. With respect to hygiene therefore the advantage is considerable. It is not less advantageous from another point of view. Everywhere that workmen want to judge of colours and their shades, in weaving factories, dyeing, and papermaking works, &c., this new light has the precious property of not changing the appearance of the colours, it preserves to even the most delicate shades their true relative value as seen by daylight. Thus many errors are avoided, which were almost inevitable in the yellow reddish light of coal or gas.

Without being altogether abolished, the danger of fire is also less with electricity than with gas. It is therefore easy to understand that the proprietors of large warehouses have not hesitated to instal electric apparatus, machines, and lamps, which display the goods with so much richness and brilliancy. The large rooms, courts and gardens of great hotels, and large banking establishments have for some years past been lighted either by arc lamps with opal globes to diffuse and soften the light or by incandescent lamps of different systems.

Trials of electric lighting are being made for other great public establishments, which are much interested in the success of these trials. We mean libraries, museums, and theatres. The great reading-room of the British Museum is lighted by electric arc lamps. Everybody has heard speak of the brilliant experiments of lighting which have taken place at the great Opera at Paris, where different systems have been simultaneously tried with gas; the great staircase, the hall, and the stage are each lit with a certain number of lamps, and there the effects of this brilliant system of lighting can be criticized. Since then, the hall of the "Variétés" Theatre in Paris has adopted the electric light. It is not so much from an artistic point of view that the adoption of this mode of lighting is desirable for the establishments that we have mentioned; it is chiefly for security from fire and on account of hygiene.

The terrible catastrophes which destroyed the Ring Theatre at Vienna, the theatre at Nice, besides others in which many victims perished, would soon become, if not impossible, at least difficult with electric lights. The certainty of this quasi-impossibility, by reassuring the spectators, would probably prevent the occurrence of panics, which claim more victims than fire.

In speaking of this application of electric lighting we have in view lighting properly so called: the question is very complex because of the many, and often contradictory, demands which theatrical managers make. On the contrary, if the electric light is only wanted to produce on the stage certain striking effects, that is another question.

In 1846, at the first representation of *Le Prophète* at the Opera in Paris, it was employed to produce the effect of the rising sun, and the success was complete. In 1860, at the revival of *Moses in Egypt*, Duboscq obtained, with the voltaic arc and a convenient combination of lenses, screens, and prisms, a rainbow, which is very difficult to imitate by the old methods; besides fires, flashes of forked lightning, magical effects, cascades, and luminous fountains, &c. For these special applications the light was produced, not by electric machines, but a battery; the reason is simple—the installation and driving of machines is only practicable for lighting that is required to last for some hours. For isolated and short effects, like those just mentioned, the employment of a battery is much more simple and convenient.

§ 3.—*Electric Lighting of Ports, Tunnels, and Mines.*

The electric lighting of ports has already been of great service to navigation. The ports of Belfast, Hull, Havre, and Odessa are now lighted by electricity. At the two quays at Havre thirty-four Jablochkoff lamps, divided among six circuits, of from four to six lamps each, are fed by four of Gramme's self-exciting machines, worked by two steam-engines each of 35-horse power. The importance of this service will be best comprehended by remembering that the port of Havre is only accessible for large vessels at high-water

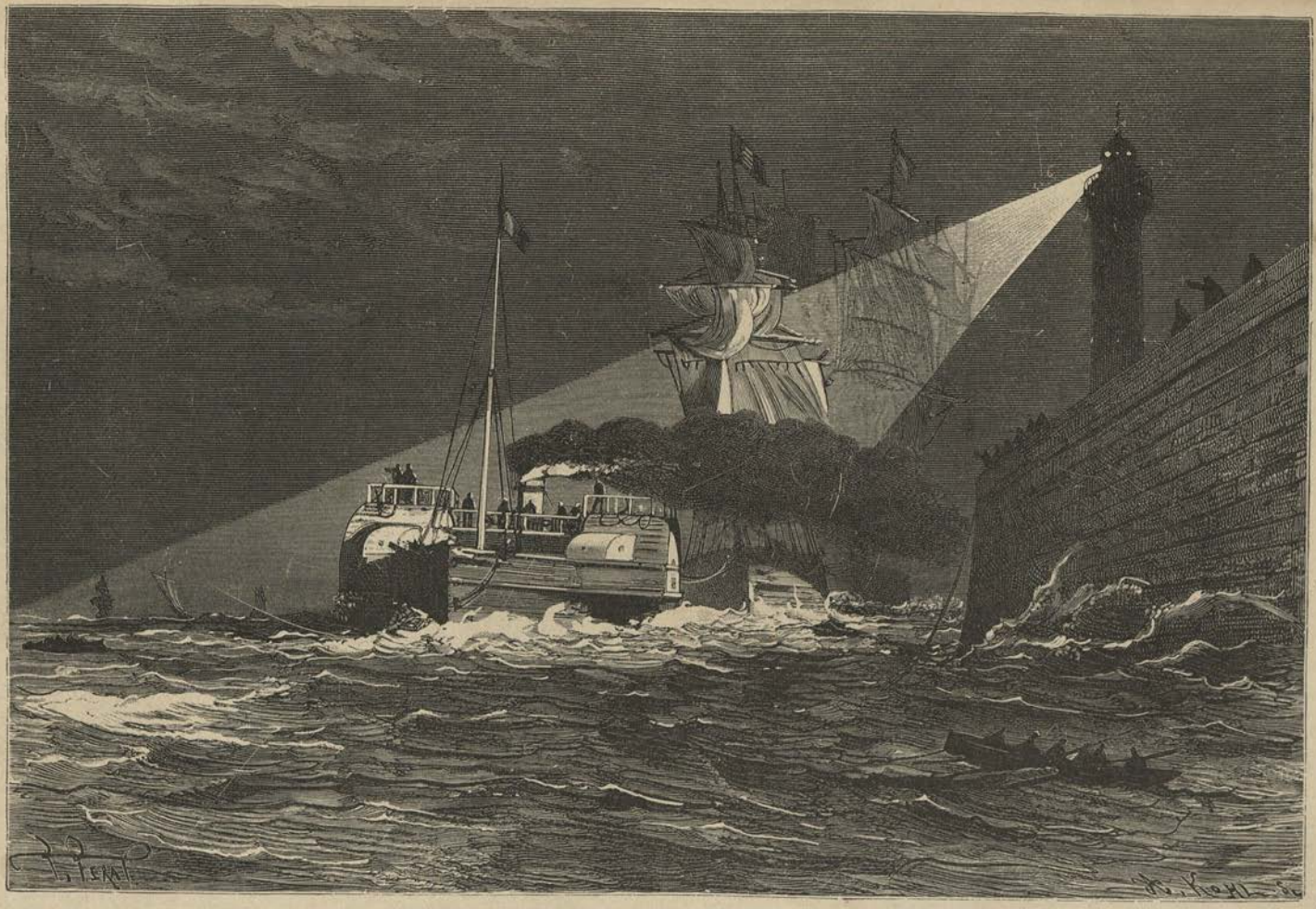

PLATE XV.—VESSEL TOWED INTO A HARBOUR BY NIGHT.

When the two daily high-waters happen during daylight, the vessel which for any reason—a high wind, for example—needs shelter, and fails to enter by the first, has only to wait for the second and thus suffer a delay of eleven or twelve hours. But when one high-water occurs at night, on missing the first tide, the captain was formerly obliged to wait twenty-four hours at anchor in the roadstead, before being able to enter. Henceforth, thanks to electric lamps, the entry of vessels can be made as easily in the night as in the day.

The docks of the port of Limerick are lighted by Siemens lamps, by which also the Albert Dock at London is lighted along a frontage of nearly four miles.

A very noteworthy application of the electric light is that of the lighting of long tunnels, like the St. Gothard, the Mont Cenis, or underground railways in large cities. But, instead of lighting up the road, experiments have been made on the lighting of the trains themselves, the locomotive being furnished in front with an electric lamp and a projector, so that the state of the road can be ascertained for some distance ahead by the driver. A special arc lamp designed by Sedlaczek and Wikullil, has been used in some of the experiments; it was fed by a Schuckert dynamo which was driven by a small Brotherhood engine, the whole being placed in the front part of the locomotive. The trials made between Paris and Dammartin on the Northern Railway and also in Germany were very successful. "The lamp," says Géraldy in *La Lumière Électrique*, "is fixed and brilliant, it allows of buildings and bridges being distinguished at a distance of 400 or 500 yards." The visibility of the signals is not altered; and the train itself can be seen at a distance of more than a 1000 yards.

The appearance of a train furnished with its electric projector is represented in Plate XVII. Railway engineers do not altogether favour this system of lighting trains. They consider that the expense of installing the light, costly as it is, does not yield proportional advantage; it is not so essential for a train to see before it; it would be preferable for a train to be seen at a distance behind—a train stopped or retarded being the most dangerous obstacle. It would be necessary then to place the electric light behind, and this offers many difficulties.

Experiments have been, and still are being made on lighting

carriages with electricity. In this case, the employment of incandescent lamps and their excitation by means of batteries, or better by accumulators, was naturally suggested in preference to arc lamps. In England trials have been made with Faure's accumulators. On the Eastern line of France, the compartments of a train have been lighted by thirty-one Maxim lamps, which received their current from a Gramme machine; this latter, placed in the front waggon, was driven mechanically from the axle. When slackening speed and stopping the current of the Gramme machine ceased, three series of accumulators taking its place. Each of these series of twenty-four De Meritens accumulators was also united to the machine, and charged by it whilst the train was in motion.

If, in order to avoid accidents and collisions on railways, and to discover obstacles, the employment of a powerful light is desirable for the same reason, but still more urgently, it is well to apply the electric light to ships. Collisions at sea, especially in foggy weather have increased with the development of navigation in a truly deplorable degree, and many catastrophes the terrible results of which are still present to the memory of all argue in favour of this application.

The first experiments were made fifteen years ago. Berlioz, the director of the Alliance company, installed on the yacht the *Prince Napoleon* a Malderen machine, furnishing light by an arc lamp fixed at some yards above the deck, and provided with a projector which directed the luminous rays horizontally. The success of these first experiments led to similar installations on the vessels *St. Lawrence, Le Forfait, Le d'Estrées, La France, l'Aigle, l'Hirondelle.* But various inconveniences, one of the principal of which consisted in the disappearance of the regulation green and red lights in presence of the greater intensity of the fixed electric light, have caused these first methods to be abandoned. Since then, new experiments have been made, under the direction of Fontaine, on the transatlantic boat *l'Amérique*, others by Messrs. Sautter and Lemonnier on the Russian ships *Livadia* and *Peter the Great*, the French ships *le Suffren*, and *le Richelieu*, and lastly by Dalmau on the Spanish vessels *Numancia* and *Vittoria.* The generators employed are usually Gramme machines driven by Brotherhood engines, and the projectors are one of the systems either of Sautter and Lemonnier, Mangin, or

PLATE XVII.—THE ELECTRIC LIGHT ON RAILWAYS.
Locomotive Lighting the Track.

Siemens. We represent these different apparatus in Figures 538, 539, 540, and 541.

In the expedition to Tunis, the French vessels were furnished with the necessary apparatus for the production of the electric light, and we shall see in the following chapter that they made frequent use of it. We already know the Gramme machine (Fig. 538 gives the D type of it). We will now give some details on the apparatus for projection.

The Sautter and Lemonnier projector (Fig. 539) contains, in a

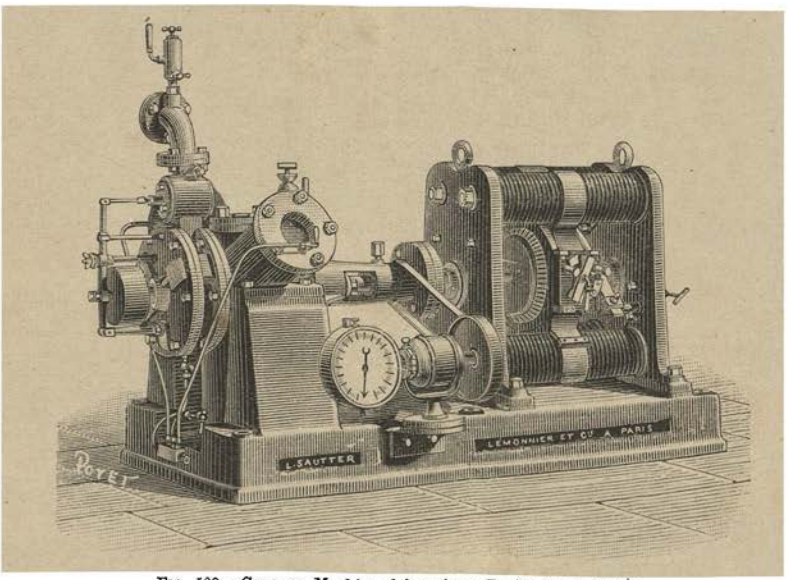

FIG. 538.—Gramme Machine driven by a Brotherhood Engine.

cylindric drum, a lenticular apparatus, like that of electric light-houses ; only the optical system is built up so as to concentrate and project, under the form of a cylindrical beam, the rays of the voltaic arc emanating from a Serrin lamp. The metal drum which supports this optical system is movable round its vertical axis, and can oscillate round its horizontal axis, without the relative positions of the lenses and the luminous point changing. The combination of luminous rays can thus be sent in all directions, and at all inclinations.

The projector also can be installed in any part of the vessel, either on the bridge or on a platform arranged in the front.

In the Siemens projector (Fig. 540), the projecting apparatus is a parabolic reflector, and the two lenticular systems which accompany it are used to regulate the lamp by projecting the carbons on to a screen. The Mangin projector (Fig. 541) is composed of concave, spherical mirrors, but the interior surface is the reflecting surface, so

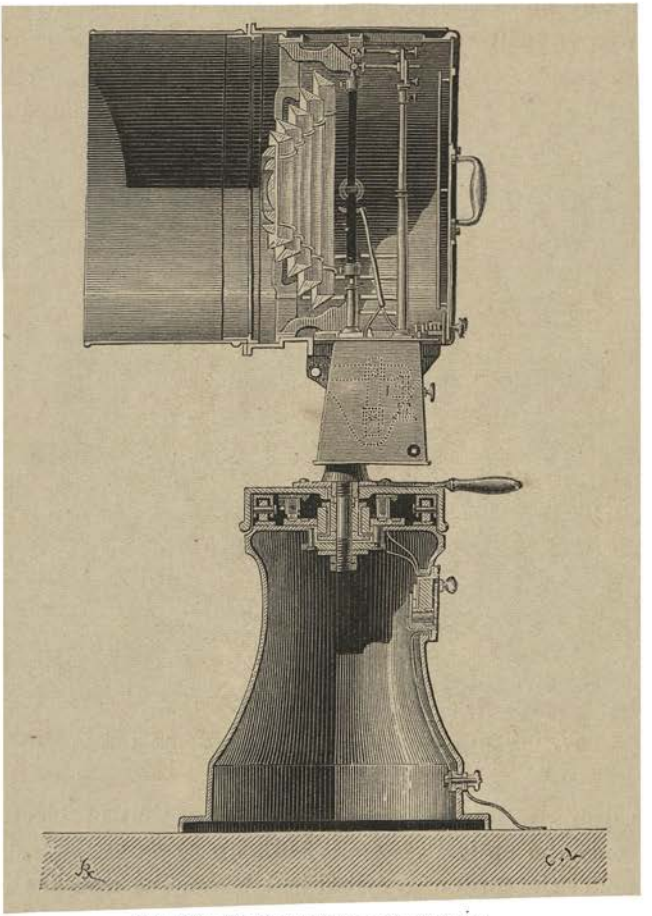

FIG. 539.—Sautter and Lemonnier Projector.

that the luminous rays traverse double the distance between the mirrors before being sent outside. The outer and inner surfaces of the mirror not belonging to spheres of the same radius, the inventor has calculated their radii, so as to bring the reflected luminous rays to parallelism. His aim was to avoid the employment of costly lenticular apparatus,

and parabolic reflectors, the form of which is difficult to obtain with precision. The carbons are moved by hand, by the aid of screws at different places, because of their unequal wear. There is no regulator, so that the watching of the apparatus at work must be constant. The aim has been to suppress all delicate mechanism, because even that does not dispense with a certain amount of watchfulness.

The electric light employed in the navy, as we have said, does not light up the vessels; on the contrary, the ship itself remains in

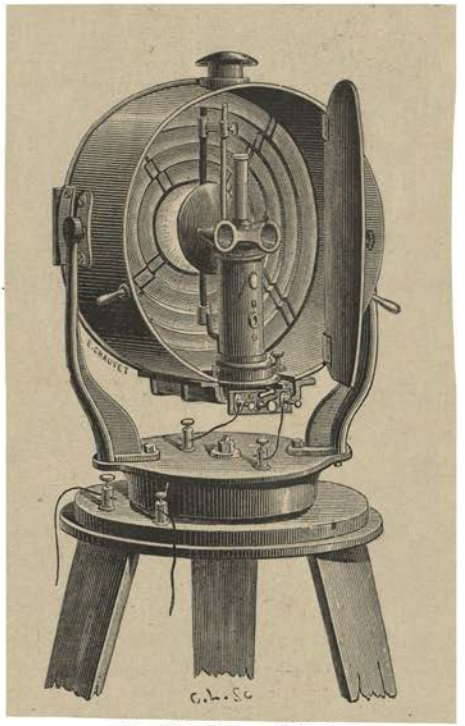

FIG. 540.—Siemens Projector.

obscurity, and the light which it carries illuminates its path and proclaims its presence to other vessels in the same waters, or serves to explore the horizon. As for lighting the interior of the vessel, that is quite another thing. This question has also been attacked for some years past, particularly since the invention of incandescent lamps.

The mail steamers of the great transatlantic lines first gave the signal. The *City of Richmond*, the *Servia*, the *Château-Léoville* and

others were lighted by Swan lamps; six electroliers with thirty lamps illuminated the large saloon of the first of these vessels, and eleven other lamps served to light other parts of the vessel. Since then hundreds of vessels have been fitted with glow lamps, and many compact ship-lighting plants have been devised.

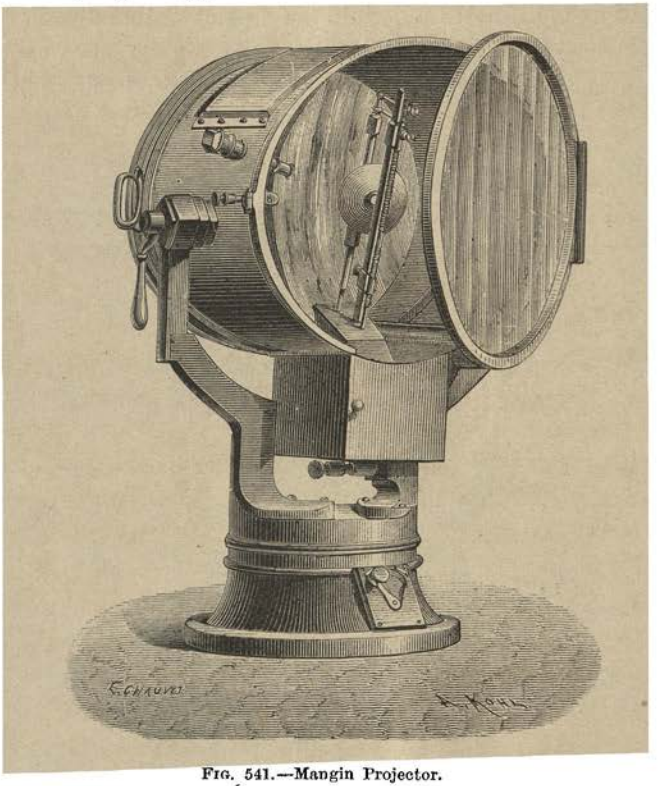

FIG. 541.—Mangin Projector.

§ 4.—*Electric lighting of Towns, Streets, Squares, and Public Monuments.*

In spite of the incontestable success of experiments, already numerous and prolonged, having for their object the substitution of electric light for gas in lighting public places, streets, quays, ports, &c., the new system is not yet fully accepted. But the difficulties and the obstacles no longer belong to the domain of science; it is only now a

question of economy and of commercial profit. Since the time, relatively recent, when the first and not very important experiments were made by the lighting of Waterloo Bridge and the Thames Embankment in London, the avenue and the squares of the Opera, the Carrousel and the Théâtre Français in Paris, what progress and what practical improvements have been made in apparatus, lamps, and machines! An idea of this can be gathered from the preceding chapter. Most of the faults of the electric light, such as unsteadiness and the lights being too powerful and blinding, have been avoided. We have still to compare and appreciate the different systems in all their bearings. Nearly all were seen at work at the Exhibition of Electricity or at the Opera in Paris in 1881, but the confusion of lights rendered a carefully considered judgment difficult. It is only long continued experiments, like those which have since been made in many large cities, which permit electricians to pronounce with certainty, and the public, which only judges by effects, to arrive by habit at a wholesome appreciation of the new mode of lighting.

What is now a settled point is that arc lamps, fed by the powerful dynamos now known, are much more economical than incandescent lamps, and even than gas, whenever it is necessary to obtain light of considerable intensity. This we have clearly seen in connexion with lighthouses, the lighting of great workshops, timber yards, ports, &c.

It is true that in proportion as it is divided the light is more costly, and this explains the hesitation of public authorities in lighting up avenues, roads, and squares. But admitting that the price of the electric light continues decidedly in excess of that, of equally luminous intensity, obtained by gas, still it is probable that lighting by electricity will be adopted in the principal streets of cities, and in those parts inhabited by the rich; in this case it will be a luxurious light, and the advantages of a more abundant and whiter light will be appreciated more than the inconvenience of great expense will be felt.

As for theatres and concert-rooms, as the case may be, sometimes arc lamps and sometimes incandescent lamps are preferred.

With regard to private lighting all considerations are subordinate to the question of the distribution of electricity to the houses of the consumers. The Americans, bolder than Old World people, seem

to advance before us in this respect. In describing Edison's large machine, we saw that a project of lighting a whole quarter of New York was an accomplished fact.

This fruitful inventor devised a complete system of mains and distribution of currents, and of division, of the electric light. In the central station, established in the middle of the district, twelve steam-engines drove as many dynamos, each capable of feeding, as we have already said, 2400 lamps of 8-candle power, or 28800 lamps of the first type, or 14400 of the second. In 1884 an English electrician, Gordon, constructed a great dynamo-electric machine powerful enough to absorb 500-horse power, and to feed from 5000 to 7000 incandescent lamps. Large dynamo machines requiring from 50 to 500 horse-power to drive them are now quite ordinary affairs. For the great lighting station at Deptford, which is to furnish current, by means of transformers, to a large area in London, Mr. Ferranti has constructed two large machines, each requiring, at full duty, 1500 horse-power. The same engineer is now constructing two others, each of which will absorb over 8000 horse-power, and furnish current to about 100000 glow-lamps. The rotating armatures of each of these machines will, when completed, weigh about 550 tons. These machines far exceed in dimensions anything attempted in any other country.

The time has now arrived when the problem of the distribution of electricity to houses and consequently that of private electric lighting is being successfully solved. It will be for experience to pronounce on the advantages and relative inconveniences of the various modes of supply devised by rival inventors.

CHAPTER XIV.

ELECTRICITY IN WARFARE.

§ 1.—*The Electric Telegraph in Military Operations.*

WHEN once the existing telegraph lines had been used for the transmission of orders and for rapid communication between the various corps of an army, it was very natural that, considering the advantages of this application of electricity for all purposes of communication, it should be carried a step further, and that a special military telegraph service should be established. The travelling telegraph was first employed by the French armies in the year 1857 at the conquest of the Grand Kabylie, by Marshal Randon. During their great civil war the Americans constantly used this method of correspondence for the service of the armies in the field. The German troops in 1870 and 1871 were from the beginning of the war accompanied by brigades of telegraphists perfectly trained in the running of telegraph lines and their working, and whose services were used not only for purely military operations but also by the commissariat department. We append some details of great interest which we have extracted from the work of Ternant on *Telegraphs*, and which relate some of the results of Prussian military telegraphy during the war of 1870, as observed by a German engineer named Von Chauvin.

"In Prussia," he says, "during peace numerous operators drawn from the offices of the civil service were trained in the services necessary in war. Shortly after the opening of the campaign 300 telegraphists were ready to start with the vanguard of the army, and

communication was promptly established with the rearguard. The corps of telegraphists was supplied with the apparatus of the Morse system, and the sounder was never used. The brigade accompanying the vanguard was supplied with light posts and copper wire, and also used insulated wires or cables laid upon the ground, or better still, suspended along the highways. The Morse apparatus was about the same weight as that used in the civil service.

"A second brigade established a somewhat heavier line upon slightly stouter posts, thus supplying communications by means of which stores and munitions of war could be requisitioned from Prussia. A third brigade of telegraphists following the rearguard in its advance upon French territory, changed the temporary lines of the second brigade into permanent lines of the same strength and dimensions as those employed by the Government. The usefulness of the telegraph was demonstrated during the sieges of towns and fortresses. A circuit of ninety miles of telegraphic lines encompassed Paris, and it is easy to understand that this space could not be filled with soldiers. Two aërial lines were also established outside the range of the French projectiles. Each of these consisted of four wires connecting twenty-four different stations, and thousands of despatches were transmitted every day around Paris. The German Emperor expressed the opinion to Moltke that *without the telegraph it would not have been possible to besiege Paris or to maintain the siege of Metz for so long a time.* Another advantage of the telegraph is made manifest in the direction of the victualling and the carriage of war material by means of telegraphic communications. All the provisions for this immense army were drawn from Germany; for it was not possible to find sufficient rations in the country occupied."

At the present time a military telegraphic service is organized in all European armies, in France, Austria, England, Italy, Russia, &c. At the Electrical Exhibition in Paris in 1881 there were exhibited models, carriages and material adopted by these different countries. The installation of a military telegraphic line involves a small number of operations; the carriage and unrolling of the wires, the fixing of the poles, if the line is an aërial one, and the installation of the signalling stations. America and Sweden employ three carriages for these purposes, one to carry the wires or cables, another for the

poles and the insulators, and a third for the apparatus of the signalling station. Belgium uses a single carriage, but this is only where the line is laid directly upon the soil without insulating poles; it is divided into three compartments, an uncovered section, the signalling station, and the part where the cables are placed.

The unrolling of the wire is usually accomplished automatically. A windlass driven by the wheels pays out the wire proportionately with the advance of the carriage. In the English carriages constructed for the field telegraphs there are two rows of three coils of wire turned by means of pulleys which connect their axles to the axles of the wheels. These coils are placed at the rear of the carriage; in front under the driver's seat are the boxes containing the battery, the signalling apparatus and the galvanometer. Lastly, in the longitudinal space between the two rows of coils are placed twenty light poles, cast in parts which fit into one another, and which are drawn out like the tubes of a telescope when they are placed in position.

We shall now describe the French method of installing a military telegraphic line. The material is contained in a travelling telegraph office divided into two compartments, one of which serves for a signalling office and the other contains the coils of wire. The length of the wire on the coils being about ten miles, for greater distances these travelling offices are preceded by waggons carrying coils of wire, as well as poles and tools of all kinds used in the work. When the country is mountainous and inaccessible to carriages, the materials are carried on mules, and for the purpose of unrolling the wires wheelbarrows are provided upon which the coils are placed.

Each working party consists of a non-commissioned officer, two corporals, and twelve men. The sergeant in advance traces out the course of the line, and the soldiers are divided into three groups, one of which digs the holes for the poles when the line is aërial, the second unrolls the wire from the coils and splices and makes joints, whilst the third attaches the wire to the poles and erects them. From Plate XVIII. an idea can be formed of the various operations involved in erecting a military line.

We have as yet said nothing of the apparatus employed for the transmission and receipt of despatches. The Morse system is ordinarily used; yet in the United States the message is read by

sound; that is to say a "sounder" is used as a receiver, according to the custom in America, on an ordinary telegraph line. Without being more simple or less bulky than the Morse writer, the sounder has one serious difficulty in the field—it leaves no written record of the despatches, a matter which is very important in fixing responsibility. In France the sounder is only employed for reconnoitring, for operations connected with the installation of the lines, or for stations set up on the march. For other purposes the despatches are written in cipher; for communications which can be given verbally the telephone can

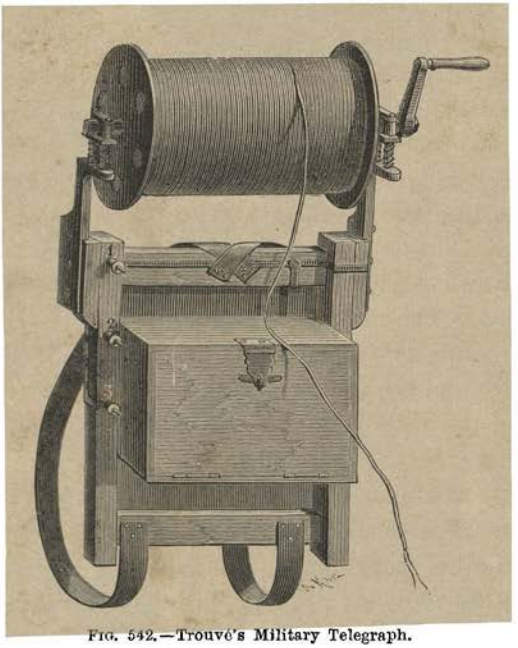

FIG. 542.—Trouvé's Military Telegraph.

render important service. Thus magnetic telephones are generally at hand in all the military telegraph stations.

For communications over small distances or for what may be called a flying telegraph, M. Trouvé has devised an ingenious set of apparatus of great simplicity, which can render important services in the field by the side of the more elaborate system just described. Two correspondents, an officer or non-commissioned officer and a soldier, are the two posts or stations; each of them is furnished with a battery and a transmitting and receiving apparatus. The line is formed by a

PLATE XVIII.—MILITARY TELEGRAPHY.
Erection of a Field Line.

cable of two wires,[1] coiled upon a large bobbin fixed in bearings on the top of a framework (Fig. 542) which the soldier carries upon his back like a knapsack; the wire is unrolled upon the ground at the same rate at which the bearer walks forward. Below the bobbin is a box containing the battery which is composed of Daniell's cells; the officer carries a similar battery in a pouch. Each of the two correspondents has a piece of apparatus to which three wires are attached, one joined to the battery, and the other two to the two wire conductors of the line. Figure 543 represents the "receiver," which also carries a transmitter or Morse key fixed to the exterior of a box in the form of a

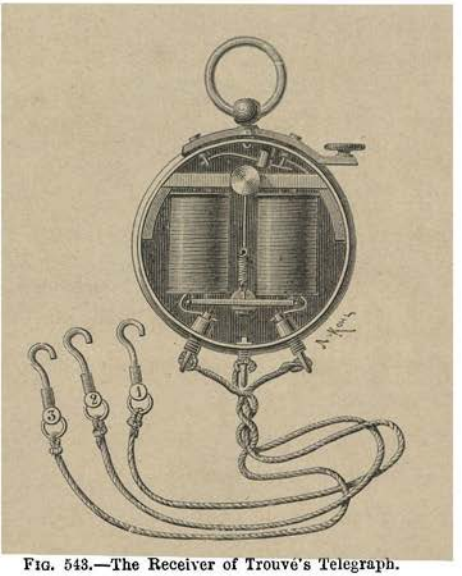

FIG. 543.—The Receiver of Trouvé's Telegraph.

watch and inclosing an electro-magnet with its armature. The transmitter is easily worked with the fore-finger of the right hand, whilst the left hand holds the box. The Morse signals so transmitted to the line cause corresponding movements of the armature of the receiver, which, in striking against a button mounted upon the bottom of the box, produces a series of long or short sounds. The despatch is read by listening to these sounds.

[1] The two conductors which form the going and the return wire are insulated, covered with gutta-percha, and are bound together with india-rubber tape. The cable so protected can be laid upon dry or wet ground, or can be exposed to rain.

M. Trouvé has constructed another piece of apparatus, which he calls a *Telegraphic Watch* (Fig. 545). It is a kind of dial transmitter

FIG. 544.—Method of using the Trouvé Apparatus for Military Telegraphy.

FIG. 545.—The Telegraphic Watch.

and receiver, which is worked by turning a movable button like that which is used for winding keyless watches.

§ 2.—*The Electric Light in Warfare.*

In Chapter XIII. we have described the apparatus which is used on large vessels to project a strong luminous beam of electric light towards any point of the horizon either to illuminate the ship's course or to guard against collisions. It is easy to see that the same apparatus can be utilized in time of war, for reconnoitring, for night works either by land or sea, and for the production of signals.

A special service of this kind was organized in 1871 during the siege of Paris by the Prussians. Foucault arc lamps were adopted for the production of the light, but at that time magneto-electric machines were not in common use, and except in the case that we are going to describe, recourse was had to a battery. "The lamp," says M. Saint-Edme,[1] "was placed in a special case with movable shutters so as to produce at will rapid intermittent lights; the beam was reflected by a powerful mirror so placed that it could be made when desired either convergent, parallel, or divergent. A battery was necessarily the electric generator employed; there were no magneto-electric machines, and moreover before the end of the siege the coal required for the steam-engines was exhausted. Only the beacon of the Montmartre redoubt was provided with current from a magneto-electric machine (Plate XIX.). The arc supplied with current from the magneto-electric machine was necessarily much more intense than one supplied from nitric acid batteries, composed of fifty cells, since this machine was equivalent in effective power to 100 of these cells. This beacon, skilfully handled, swept the plateau of Argenteuil with its rays, and plunged its beam even into the redoubt at Orgemont, situated more than six miles away as the crow flies. The Germans in vain tried repeatedly to surprise our forts during the night; the electric light kept good guard.

"Similarly the besiegers employed the voltaic arc either to study our night works, or to illuminate the fire of their batteries; the luminous beams sufficiently indicated that, on their side, the generator of electricity was of the magneto-electric order. The

[1] See *L'Electricité appliquee aux Arts Mécaniques, à la Marine, au Théâtre.* Paris, 1871.

ability displayed in the installation and working of the apparatus proved also that the superintendents were learned electricians."

Nineteen years have elapsed since that terrible year when the defenders were obliged to improvise the means, whilst the attackers had long studied and premeditated upon them. Let us hope that we have profited by the teachings of experience and that our future adversaries will find us ready.

The principal occasions, during war, on which the electric light can render useful service are thus enumerated by Martin de Brettes, one of our distinguished officers. "(1) For reconnoitring a fortification the besiegers need to produce a momentary light sufficient for their purposes, but not lasting long enough to arouse the attention of the besieged. (2) For directing the fire of a battery upon a particular mark, it is necessary that this mark should be illuminated long enough to permit a good aim. (3) Then in order that they may not be surprised by the opening of a trench the besieged ought to illuminate continuously the region where this operation is likely to be executed. (4) The lighting of a field of battle, of a breach, and then of the assault, demand also a light of indefinite duration." This enumeration refers principally to the works of a siege, whether of the attack or the defence, and in this case the apparatus can be established at a fixed point.

For reconnoitrings during a campaign a movable system is necessary. For this purpose there has been devised a generating machine fixed upon a portable engine so that it can be transported wherever it may be wanted, and thus the projector can be installed at a little distance from the generator, either upon a four-wheeled carriage, or supported upon a stake. Figure 546 shows the system adopted in France for this purpose; it consists of a Gramme dynamo machine driven by a three cylinder Brotherhood steam engine. Very interesting experiments have been made with a similar system and have given excellent results. We shall cite, in the words of M. Hippolyte Fontaine who speaks as an eye-witness, those which were obtained at the fort on Mount Valerian by a commission of French officers. "Employing," he says, "a Gramme machine, which coupled in series gives 14,250 standard candles, and coupled in shunt 23,750 standard candles, there are rendered visible for the observers, placed near the apparatus for projecting the light,

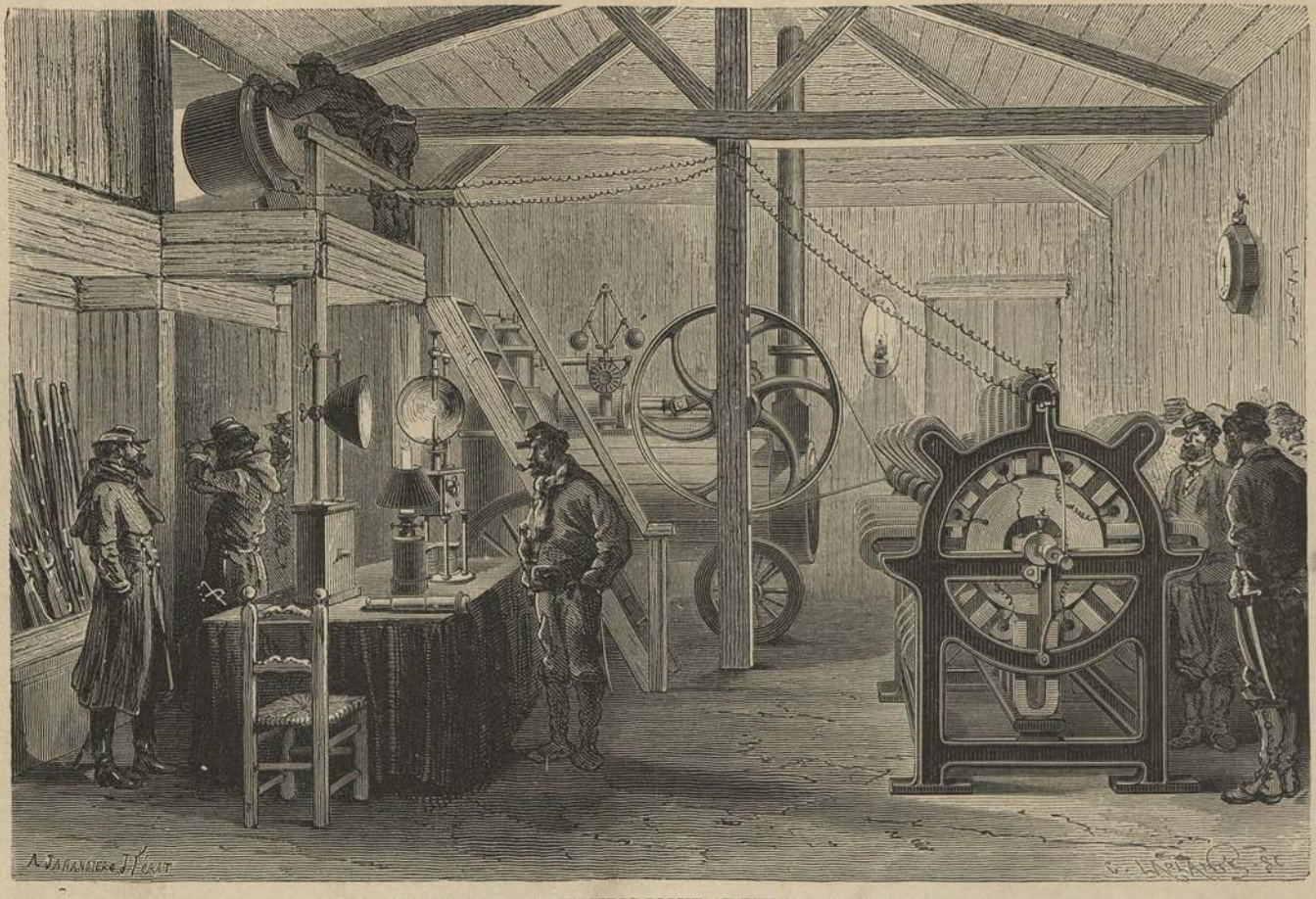

PLATE XIX.—THE ELECTRIC LIGHT AT THE SIEGE OF PARIS.

The Montmartre Redoubt.

movements of troops, and houses and carriages at a distance of 5,500 yards; at a distance of 3,000 yards soldiers can be observed, and it is possible to notice them fencing with their bayonets." Other experiments, not less favourable, have been made at Toulon and Cherbourg. The photo-electric apparatus were constructed by Messrs. Sautter and Lemonnier, and were combined with a Mangin projector as already described. It has been unanimously admitted that the complete apparatus constitutes an efficacious protection against torpedo boats

FIG. 546.—Portable Electric Light Apparatus for Reconnoitring.

which try to pass through a channel (like that of La Carague at Toulon). "These vessels were discovered in time to be destroyed by the fire of the forts, and officers placed at special points could direct the explosion of sunk torpedoes at the exact moment when the enemies' boats came within their range of action. A light haze prevented the atmosphere from being absolutely pure." (H. Fontaine *Éclairage à l'Électricité.*)

The electric light which we have seen installed upon ships for the

production of signals can render the most remarkable services in the operations of a naval war. Most of the ships of the French fleet which took part in the expedition against Tunis were furnished with the dynamo-electric machines and the projecting apparatus described in the preceding chapter. From the commencement the frigate *La Surveillante* used its light to illuminate suspected points of the Isle of Tabarka. Afterwards the same use of the electric light was made by various war ships for the nocturnal illumination of Sfax, Gabès, and Sousse. Plate XX. represents this last episode of the Tunisian expedition.

We have seen that the approach of torpedo boats can be discovered by the projection of an electric beam of light from a point of the coast or port menaced. But it is easy to understand that the same means of protection is at the disposal of ships supplied with convenient apparatus. We shall not insist upon this point. We proceed to consider how in the firing of hidden torpedoes it is again electricity that is utilized. We therefore propose to conclude this chapter with a final paragraph which we shall not devote exclusively to the military side of the question, but to the firing of mines generally, whether this has a special industrial object or not.

§ 3.—*Explosion of Torpedoes and Firing of Mines.*

The firing of shots in mines by the old methods is often a dangerous operation, and the accidents that it has caused at various times are unhappily too serious for us not to think of endeavouring to prevent them. To light the powder inclosed in one of these charges, the following plan was pursued. A communication was made with the interior of the mine by means of long or short trains of powder, placed on the surface of the ground in earthen tubes full of powder, and which in technical language are called fuses. Then at the end of this train there was put in contact with it a long piece of tinder which was lighted at the opposite end, the dimensions of this tinder being calculated so that the workmen charged with the operation had time to escape. It was useless to insist on the danger which would result from lighting it too soon: frequently the delay necessitated by this

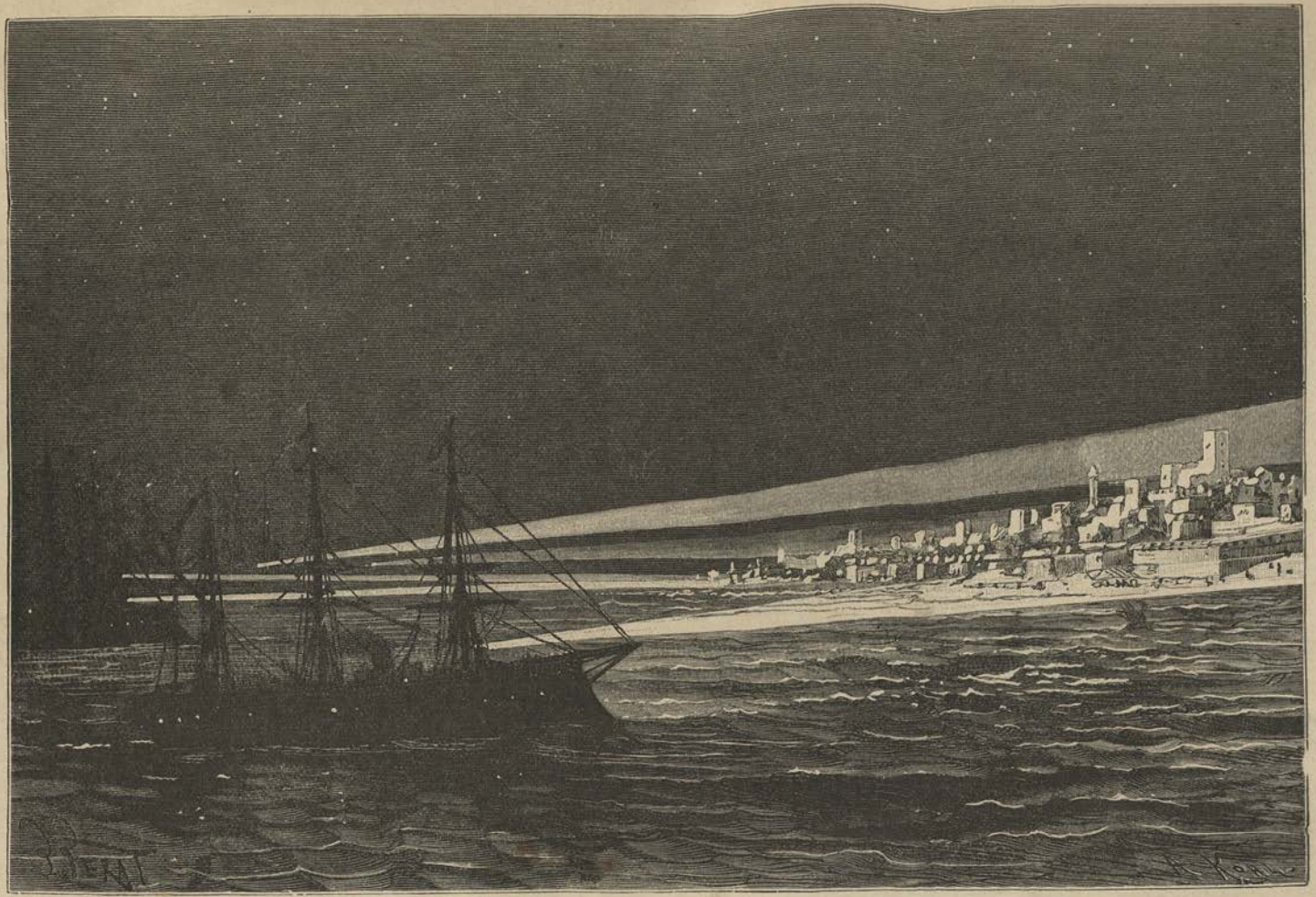

PLATE XX.—THE ELECTRIC LIGHT IN TUNIS.
Illumination of Sousse by the French Fleet.

lighting was the cause of accidents, particularly if several mines were sprung at the same time, or if it were not known which had already exploded, or if the light in the tinder was thought to be out when really it was not.

In using electric currents, with the spark that passes at the moment that the circuit is closed at a distance, all danger disappears. For this purpose sometimes a battery is employed, sometimes a Ruhmkorff's induction coil, or the induced currents of magneto-electric machines.

From the beginning of this new application of electricity the battery has been used, but a powerful battery and metal conductors of large diameter are necessary. A spiral of platinum covered with the powder is made incandescent as soon as the circuit is closed, and the explosion takes place. The battery now used is made up of bichromate of potash cells (Fig. 547), inclosed in a case, and arranged so that a very simple mechanism plunges at once all the zincs into the liquid. This method, which had been abandoned for others which we will describe, has been improved and used again more recently. The method of firing the powder in mines, by the induction spark from a Ruhmkorff's coil was first used in the great works of the port of Cherbourg. This method, proposed by Du Moncel, did not succeed at first, the calorific power of the spark, at the distance where the explosion ought to take place, not being great enough to light the powder. Happily an English engineer, Statham, invented a much more inflammable fuse than those commonly used; Ruhmkorff adopted this and the success completely justified his expectations. We shall now describe this new kind of fuse.

It is composed of two ends of copper wire, surrounded by a layer of gutta-percha, and the two extremities of which A, B (Fig. 548) are, after having been bent, introduced into a sort of capsule of vulcanized gutta-percha.[1] The two ends are placed one-thirtieth of an inch from each other, in a kind of box CD which is filled with powder, the points having been previously covered with fulminate of mercury.

"The first great trials," says Du Moncel, "of the application of Ruhmkorff's induction coil in mines were made in 1853, by the

[1] That is to say of gutta-percha combined with sulphur. The contact with copper wire causes a deposit of sulphur which is very inflammable.

Spanish Colonel Verdu, in the workshops of Herkmann a maker of gutta-percha-covered wire, at Villette. They experimented successively on the following lengths of wire—430, 650, 1100, 5200, 5400, 6950, 2800, 27000, and 28100 yards, and the success was always complete, either with a circuit composed of two wires, or with the earth included in the circuit. For this they employed only two Bunsen cells." (*Exposé des Applications de l'Électricité*, vol. iii.)

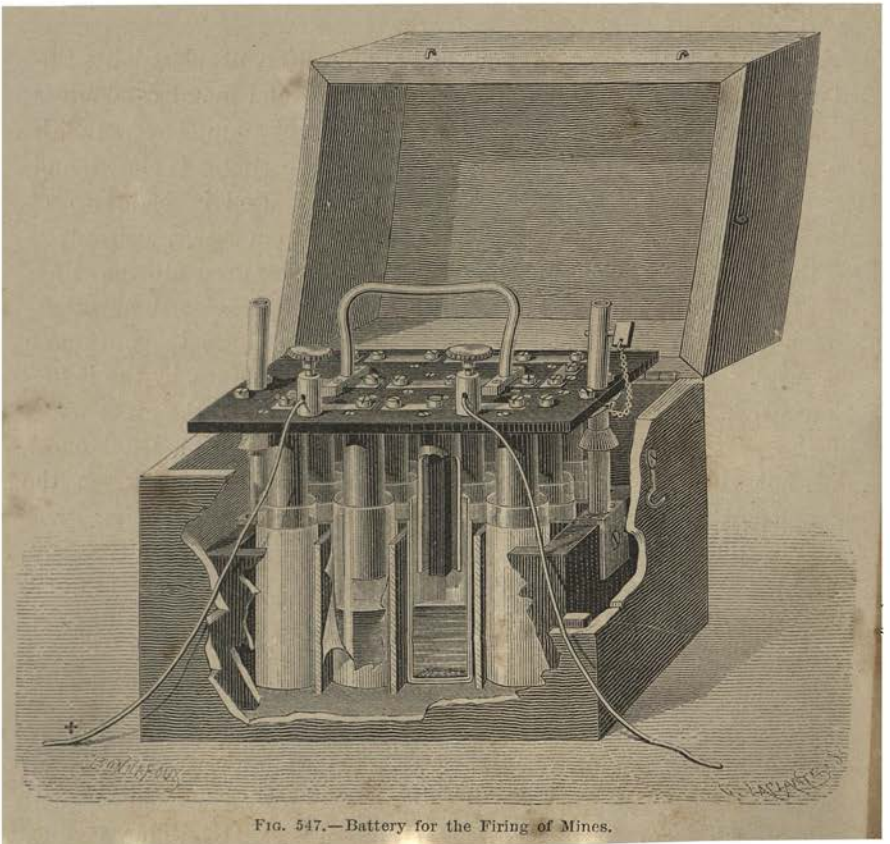

FIG. 547.—Battery for the Firing of Mines.

To fire very large mines, that is those charged with hundreds or thousands of pounds of powder, lodged in several cavities and united to each other, and to obtain their explosion almost simultaneously, a commutator is used, the key of which is successively put in contact with the copper plates of the batteries connected with each charge.

Thus the explosions take place one after the other, but at such near intervals that they may be considered as simultaneous.

Security is not the only advantage in the employment of electricity for the firing of mines: it offers also, by the facility it gives of producing gigantic mechanical effects, due to the simultaneousness of the explosions, great economy over the old method. In 1854 in the work of digging a basin in the port of Cherbourg, the explosion of six mines was enough to detach at one stroke a block of 37,500 cubic yards of rock.

We shall next describe an exploding apparatus, the calorific power of which is due to the development of induced currents

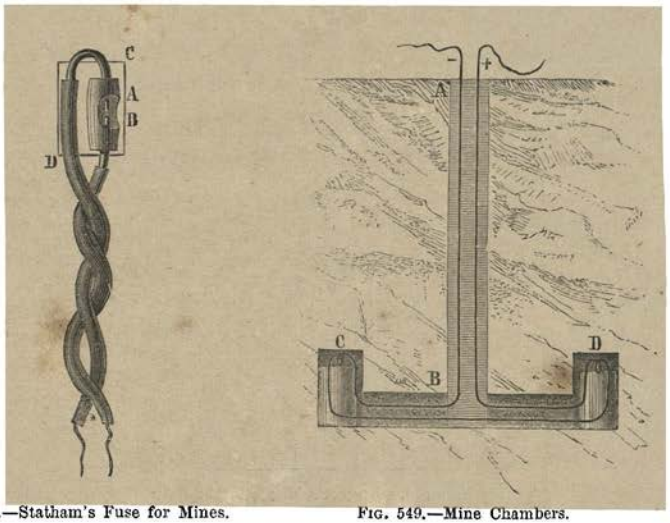

FIG. 548.—Statham's Fuse for Mines. FIG. 549.—Mine Chambers.

and of the magneto-electric extra current. The invention is Breguet's.

An electromagnet has its poles opposite two powerful horse-shoe magnets, so arranged as to have their poles turned in contrary directions. The result is that the iron of the electromagnet is magnetised and its magnetism is increased by a fixed armature. In front of the electromagnet is a piece of soft iron, maintained in contact with the poles by an opposing spring, and which can be suddenly separated from it by a rapid movement started by pressing a button.

This separation, by the diminution of magnetic induction which

results from it in the cores of the electromagnet, gives rise to an induced current in the wires of the coils, and the movement generates an extra current, the intensity of which is added to that of the induced current. It is more particularly the power of the extra current that is used for the production of the spark, and Breguet has designed an arrangement allowing this power to be used at the precise moment when it acquires its maximum value. For this purpose, a spring plate, in contact with a screw, becomes separated from it at the end of the movement of the piece of soft iron. Now the wires of the coils of the electromagnet finish, one at the screw the other at the spring, so that, whilst the contact lasts, the circuit

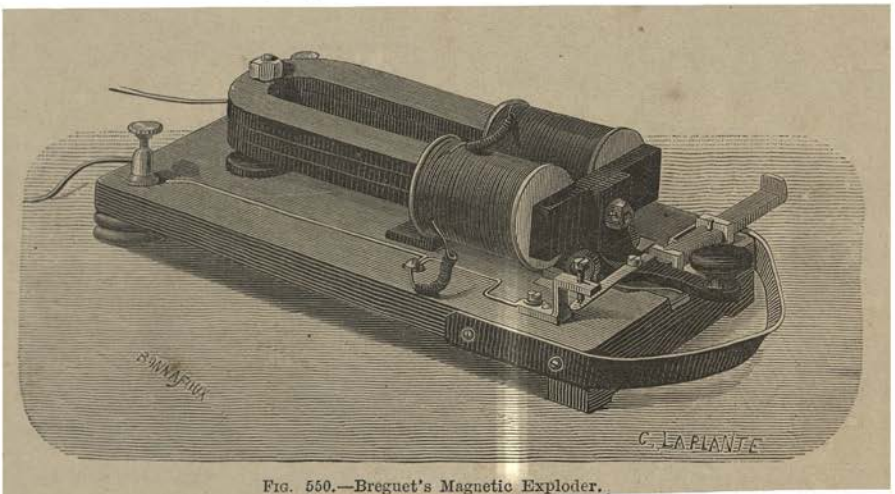

FIG. 550.—Breguet's Magnetic Exploder.

remains closed on itself, and the extra current reaches its maximum when the contact ceases; and at that moment the discharge is made through the circuit that passes through the mine that is to be exploded.

To avoid accidents, when the apparatus is put in communication with several mines, a bolt prevents the movement of the handle; it can only work when, all being ready, the bolt is drawn out. The signal can then be given without fear.

The apparatus we have just described may be and often are employed not only to spring mines, but to fire at a distance any dangerous machines or gaseous matters such as firedamp, or it may be

used simply to light gas-jets which serve as signals. A naval officer, Trève, proposed the adoption of a nautical telegraph in the fleet, destined to replace the night signals, which, as is known, are made by the help of the lanterns. These lanterns are furnished with lenses like the lenses of lighthouses, and are hoisted on one or two of the fore-yards at the highest part of the vessel. The lighting, and putting of these lights in their places take much time. M. Trève has proposed to make this mode of communication much more prompt, by replacing the candles of the lanterns by gas, and permanently fixing the lights

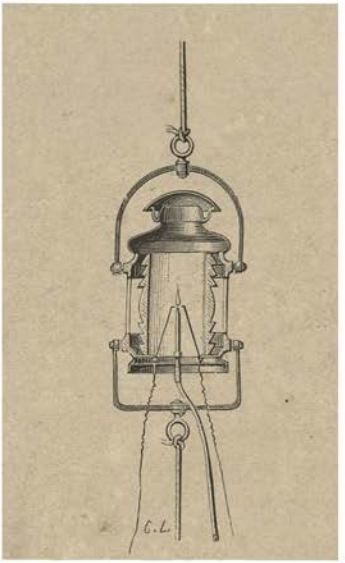

FIG. 551.—M. Trève's Nocturnal Marine Telegraph.

where they are wanted. Tubes of lead or india-rubber connected with a reservoir of gas placed on the poop reach up to the lanterns; and by opening or shutting a tap the necessary gas can be furnished to the one or the other. An induction apparatus, a Ruhmkorff's coil for example, working at the same time, the light appears in those lanterns where the taps are open, and the commander from his cabin can easily send all the signals which this mode of nocturnal telegraphy requires.

The lighting from a distance of explosive matter, by electricity serves as a protection to ports and coasts, and fortified places, as we have seen already. Everybody knows those formidable engines

called torpedoes, the explosion of which is so terrible that one only if it bursts at the proper moment is said to be able to sink the largest man-of-war. Torpedoes played a very important *rôle* in the great civil war in the United States, and caused the loss of a great number of vessels. The following describes the way in which the American torpedoes were constructed and placed.

The engine was a tin case of about two cubic feet capacity, and

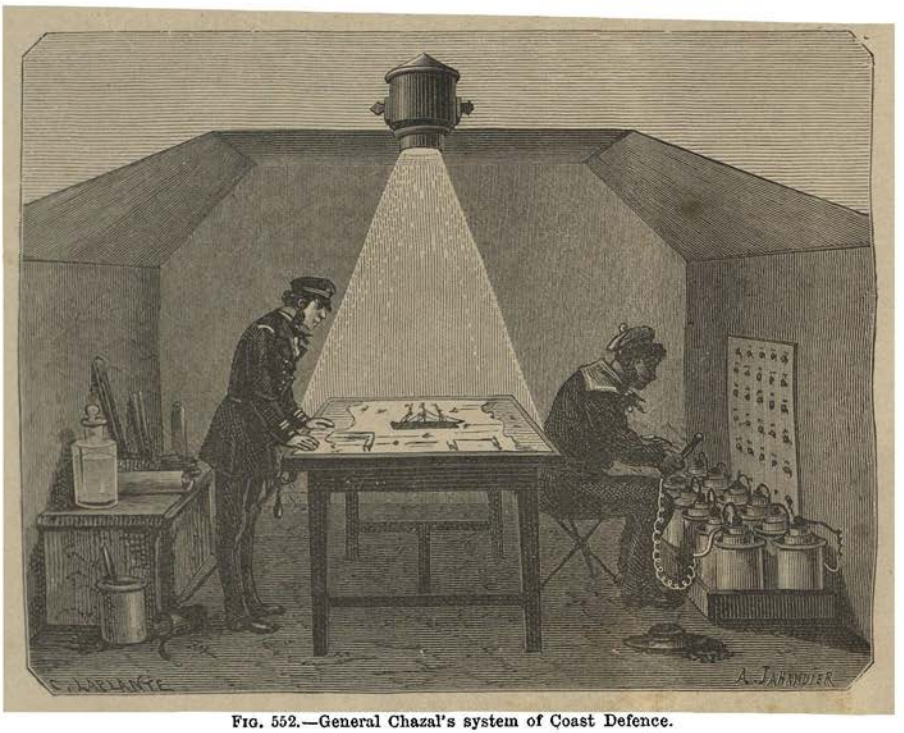

FIG. 552.—General Chazal's system of Coast Defence.

was divided into two parts by a transverse partition: one of the parts contained the powder, the other served as an air-chamber. An iron rod, covered with a capsule, dipped into the powder, and was struck with a hammer, when a vessel passing over the place where the torpedo was sunk touched a float, furnished with a cord communicating with the clock-work that actuated the hammer.

The explosion then was not originally produced by electricity. But soon it was considered that it might be advantageous to fire from a

distance, the position of the firing station being determined by the authorities charged with the defence. General Chazal combined the employment of electricity with that of a *camera obscura* in a very ingenious way for the defence of the Escaut by torpedoes.

Under a tent protected by fortifications he arranged the battery, or induction apparatus, from which the spark is produced (Fig. 552). All the wires which electrically united the lines of the torpedoes with the apparatus ended separately in the tent, and each of them was numbered so as to render all error impossible. On a table was a plan of the harbour, where the positions of the lines of the torpedoes were indicated, and which was nothing else but the reproduction of the optical projection of the river by the apparatus of the *camera obscura* placed at the top of the tent. Let us suppose that an enemy's ship is seen coming up the river; the officer watching and commanding could follow from minute to minute the position which it occupies, relative to the lines of immersion of the torpedoes. At an opportune moment he would give the order to the sailor in charge of the electric apparatus, and tell him the number of the wire of which he must close the circuit. The explosion would then take place immediately. Experiments of this kind were made some years ago, it appears, and were crowned with success. Paris, during the siege, had the front of its ramparts and forts protected by a net-work of torpedoes. But no attack of great force having taken place against the city on the part of the besieging army, this system of defence, though perfectly organized, only played a preventive *rôle*.

CHAPTER XV.

THE ART OF ELECTROPLATING.

§ 1.—*The Invention of Electroplating.*

WE have seen electricity transmit to a distance, with prodigious rapidity and under the most varied forms, the signals used in the telegraphic apparatus, sometimes limited to the simple oscillatory movements of the needles of a galvanometer, sometimes writing—printing even—in known characters the letters of a dispatch, sometimes reproducing with almost incredible faithfulness the facsimile of the writing or drawing constituting the message sent.

Telegraphy is then a mechanical application of electricity, or rather of electro-magnetism, since the principle is the reciprocal action of voltaic currents and magnets. Also by utilizing the electro-magnetic repulsions and attractions, electric clocks, chronographs, automatic registers of physical phenomena, electric motors, and a great variety of apparatus now employed in the most different arts and industries, have been invented.

The electric current not only produces movement—it heats also, and that so energetically that it melts and volatilizes the most refractory metals and substances. It fires at a distance the fuses of mines, and the protecting torpedoes of our coasts and ports. The dazzling light disengaged between the two carbon points of an arc lamp rivals in intensity the sun's rays. Thanks to a mechanism, the movement of which is regulated by the variations of intensity of the current or by those of electric pressure, the light of the voltaic arc has also been utilized in many ways: henceforth it may penetrate through fogs during the darkest nights, and lighthouses, which

previously had been of so great assistance to navigation, have been greatly improved in their brilliancy and their penetrating power.

To complete this picture of the applications of electricity, we must render an account of those which are based on the chemical effects of currents: for chemical action is in some cases the effect, in other cases the cause, of electric currents.

Electroplating and electro-chemistry are the names under which these applications are generally considered, and by which science, industry, and art, have alike profited. One word on their common principle will suffice to justify the distinction we have made.

We must first recount the phenomena which are produced when a voltaic current is passed through a saline solution. We will take for example a solution of sulphate of copper. As soon as the circuit is closed and the current is produced, the decomposition of the salt takes place: bubbles of oxygen are disengaged round the positive electrode, and copper is deposited in a metallic state round the plate which forms the negative electrode. This phenomenon of decomposition was known to the philosophers who had at their disposal the earliest of voltaic batteries; only because of the irregularity of the current, and its rapid weakening when the circuit was closed, the metallic deposit however was more often only a pulverulent deposit, unfit for industrial applications. But nevertheless from this apparent difficulty science has enormously profited and chemists have succeeded in isolating and discovering metals before unknown. The invention of constant current batteries, a Daniell for example, modified this phenomenon in a fortunate manner. We have had already occasion to mention the invention of the first electro-motor, the one designed by Jacobi to propel a boat on the Neva. If this invention had not the success which its author anticipated, it was the occasion of a more fortunate discovery, whence electrotyping has definitely sprung. Jacobi, who had employed for his experiments a Daniell battery, the positive pole of which was formed of very pure and very malleable copper plates, was astonished to see that the copper plates of the negative electrode were covered with a rough deposit, formed of very small plates of brittle copper, the internal surface of which reproduced exactly all the inequalities of the metal on which they had deposited themselves. He tried the same experiment again with some variations and obtained homogeneous metallic deposits which, instead of

being pulverulent, had all the consistency, the compactness, and the ductility of the purest metals, such as the best metallurgical operations could furnish. Moreover by replacing the copper plate of the battery by moulds of medals, plates engraved in high or low relief, he obtained faithful but reversed reproductions of the original types.[1] Such is the origin of electrotyping which an Englishman, Spencer, independently discovered earlier in the same year. Very soon this invention became greatly developed, and formed the starting-point of numerous artistic and industrial applications, which speedily received important improvements.

The processes which constitute electrotyping properly so called give deposits which are moulded exactly on the objects reproduced, but which do not adhere to them. But very thin deposits can also be obtained, which adhere to the surface of the object, and serve as a protecting layer over it without sensibly altering its shape: the methods employed in this case constitute gilding, silver plating, copper plating and nickel plating according as the metal deposited is gold, silver copper or nickel. Such is the difference as to result which exists between electrotyping and what is sometimes called electro-chemistry, or electroplating. The principle is the same, the details of the methods are different; besides, as we shall see, they were discovered quite independently of one another. The invention of electro-gilding is of a much earlier date than that of electrotyping.

In 1805 a professor of chemistry at the university of Pavia, Louis Brugnatelli, discovered the means of gilding medals and little silver objects by the aid of a battery. He used a solution of chloride of gold in ammonia, in which was dipped the object to be gilded, and this latter he joined by a steel or silver wire to the negative pole of a battery. In truth, this invention remained long unknown and unapplied, and it was the discovery of electrotyping which excited researches in this direction and revived Brugnatelli's discovery. In 1840 De la Rive, of the Academy of Geneva, after long researches made with the object of preserving the workers in gilding from the dangers of the employment of mercury, succeeded in gilding tin, copper and

[1] It was on 7th October, 1838, that the Russian philosopher was able to present to the Academy of Sciences at St. Petersburg a copper plate on which was reproduced in relief the impression of the designs engraved on a similar plate.

silver by means of a battery. The solution which he employed was a solution of chloride of gold, as neutral as possible and very dilute (from one to two grains of gold in a cubic inch), in a cylindrical bag formed of membranous bladder; this was plunged into a glass vase containing water slightly acidulated; the body to be gilded was placed in the solution of gold. A cylinder of zinc united by a silver wire to the object to be gilded closes the circuit and the electric current which should be very feeble is produced. Different improvements have been made in this method of De la Rive's, and by many others—Elsner, Bœttger, Perrot, and Smee; but a new method almost simultaneously discovered by an Englishman, Elkington (Sep. 1840), and a Frenchman, De Ruolz (1841) gave to this application of electro-chemistry a fruitful impulse. Electrotyping from that moment became a true industrial art in France in the hands of M. Christofle, who bought the patents of the two inventors. In England the house of Elkington obtained equal fame as the pioneer of the processes of electrotyping and electroplating.

Without entering into the detailed history of the phases through which electrotyping has passed in thirty years, we will describe the different methods generally employed at the present time.

§ 2.—*Electrotyping properly so called.*

We shall occupy ourselves first with the art of reproducing by a homogeneous metal deposit, not adherent and tolerably thick, any objects whatever—medals, statues, bas-reliefs, architectural ornaments, jewels, &c.

According to the end proposed, the electric reproduction of an object can be accomplished in two different ways. If you wish to obtain an identical reproduction, where the relief and the hollow are those of the model, you must begin by making a model where the hollows are in relief, and *vice versâ:* the ordinary methods of modelling are those employed; but it is clear that this first mould can also be obtained by the aid of electrotyping, and then by a second operation made with this as a negative the object can be reproduced. The first of these operations will suffice if it is a hollow reproduction of the reliefs of the model that is wanted.

In every case, the surface of the model on which the current is to deposit the desired metal must be a good conductor of electricity; which will be the case, if the mould is of metal. If, as is often the case, the mould is of wax, sulphur, plaster, gelatine or gutta-percha, the surface must first be metallized. This is done in many ways. The most simple way consists in covering the mould by means of a pencil or brush with a thin, uniform layer of powdered plumbago: Jacobi invented this means of rendering the mould a good conductor. A solution of nitrate of silver in alcohol may also be used. The surface of the mould thus wetted must be exposed to the fumes of sulphuretted hydrogen; a black, extremely thin layer of sulphide of silver, which is an excellent conductor, will thus be formed. This second method is employed when it is necessary to reproduce delicate objects, flowers, fruit, or articles of glass, or crystal. For many purposes the use of a plumbago film has been abandoned in favour of a more suitable material, namely, bronze powder, which is a better conductor of electricity.

The mould being obtained and ready to receive the metallic deposit, the bath and the electrotyping apparatus must be prepared. In what is called a simple apparatus the bath itself is a constant current battery, such as Daniell's. We shall suppose that a copper object is to be reproduced: that is the metal most frequently employed. A solution of sulphate of copper (the substance known in commerce under the name of blue vitriol) is put into a tub or into a glass vase. In the middle of the tub a porous jar is placed, filled with water acidulated with sulphuric acid, in which is plunged a plate or cylinder of zinc, forming the negative pole of the battery. It is at this pole that the mould of the object to be reproduced is suspended in the sulphate of copper solution by a metal wire, which surrounds it so as to be in contact with the conducting layer (plumbago, or sulphide of silver). Fig. 553 shows how the apparatus is arranged, which serves also for electro-chemical gilding or plating. In the latter case the nature of the bath varies, as we shall see hereafter.

The simple apparatus is then nothing but a battery, in which the mould forms the positive and the zinc the negative pole, whilst the solution of sulphate of copper surrounds the former: the metal suspension wire unites the two electrodes.

As soon as the current is established, the sulphate of copper is decomposed, and the deposit of the metal is made over the whole surface of the mould. But as fast as the deposit is formed, so the bath becomes impoverished, becoming more and more acid, and the metal deposited would lose its plastic property and coherence, if the solution were not maintained at its normal state of saturation by crystals of sulphate of copper being placed in the bath, inside a small bag.

In commercial electrotyping this simple arrangement is seldom used. Instead, there is employed the composite apparatus which differs from the simple apparatus only in the battery being outside the bath.

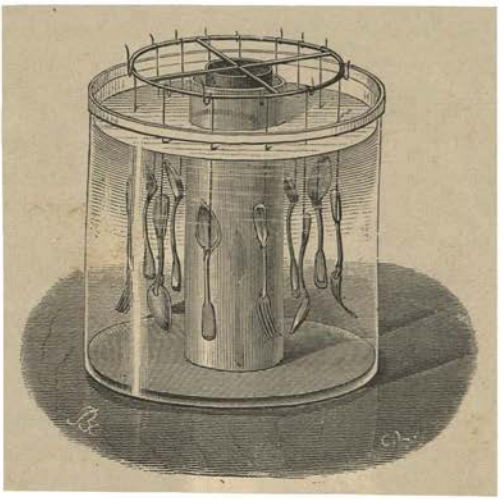

FIG. 553.—Simple Electroplating Apparatus.

To prevent the bath from becoming impoverished, a plate of copper is kept in it, which communicates with the positive pole of the battery, whilst the mould is metallically connected with the negative pole. This plate dissolves when the current passes and gives to the solution the same quantity of copper which is deposited on the object, so that the concentration of the bath remains constant. Jacobi, to whom we owe this last arrangement, called the copper-plate of the composite apparatus the "soluble electrode."

For some years the battery has with advantage been replaced by dynamo-electric machines in electrotyping workshops.

Woolrich of Birmingham, in 1843 introduced the use of magneto-electric machines, driven by steam power. In all large electrotyping establishments dynamo machines are now used. In 1872, Gramme provided Christofle for this purpose with a machine with two armatures and four electro-magnets, which, using a one-horse power, was capable of depositing 600 grammes of silver per hour. The following year the inventor furnished new type specially intended for electrotyping work and very superior to the previous one. The new machine has only one armature instead of two, and two electromagnets instead of four. Its weight is only one-fourth, and when using two-thirds of a horse-power it deposits 600 grammes of silver an hour like the preceding.

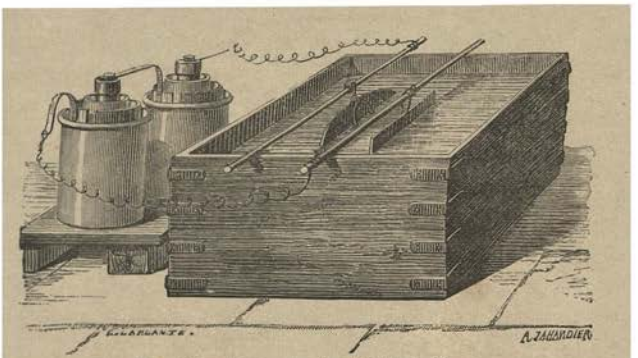

FIG. 554.—Apparatus for Electrotyping.

The dynamo electric-machines intended for this special use differ in an important point from the electric light machines. In the latter electro-motive force is more wanted than large currents; for electro-chemical operations, on the contrary, a large current is needed with but a feeble electro-motive force. Therefore wires of great conducting capacity are employed for the field-magnets and the armature. In his electrotyping machines Gramme employs a single thin sheet of copper, covering the width of one arm of the electromagnet, for carrying the magnetising current instead of the round wire which he used at first; as for the wire of the armature, it is flat and very thick, rigid enough to withstand the effects of the centrifugal force developed by a speed of 500 revolutions a minute.

§ 3.—*Different Applications of Electrotyping.*

Now we must enter into some details of the different industrial or artistic applications of electrotyping.

The methods we have described apply to the reproduction of medals, seals (as in Figs. 555 and 556), and all small pieces of which the face only is engraved.

FIG. 555.—Reproduction of a Medal by Electrotyping.

FIG. 556.—Medal Reproduced in Relief by Electrotyping.

They are used now for the reproduction of pictures engraved on wood, steel, or copper—pictures which alter or wear up rapidly when they are submitted to direct press work, whilst electrotyping allows of the original types being preserved indefinitely.

A wood-engraving gives at the most ten thousand impressions. The following is a way of producing as many copies as may be required, whilst preserving the impression. The surface of the wood is first metallized with plumbago, then an impression is taken with gelatine or gutta-percha. The mould thus taken is then metallized, and placed in the electrotyping bath; a layer of copper is deposited reproducing with the greatest fidelity the finest

lines of the engraving.[1] At the end of about twenty-four hours the thickness of the metal leaf is the twentieth of a millimetre; this is not enough to withstand the action of the typographic press, but the plate is strengthened by pouring on the reverse side a mixture of lead and antimony (the composition of type-metal). Then it is pressed, the superfluity is removed, it is mounted on wood, and the plate thus obtained is ready for the press. It will then yield, without deformation, or alteration, the impression of eighty thousand copies. As for the original type engraved on wood, it remains absolutely intact, and will furnish similar plates indefinitely.

An analogous method is used to produce plates engraved on copper or steel; generally the print itself is produced by the electrotyped proof, and with this mould the type plate can be produced. A precaution taken to avoid adherence is to expose the plate, before plunging it into the bath, to the vapour of iodine. It is thus, for example, that postage stamps are printed. Two or three hundred impressions, or moulds, taken from the original engraving are united together, and from them are obtained plates which allow of the printing of sheets representing the same number of postage stamps. The utility of this multiplication of the primitive type will be comprehended when it is remembered that in France alone more than two millions of postage stamps are used every day. To avoid counterfeits, the paper on which the stamps are made is covered with white safety ink, which is transferred to the lithographic stone in the lines of the design: on printing off only one uniform pattern of the impression covering the whole sheet is obtained.

It was by the aid of electrotyping that Smee made plates for the typographic printing of Bank of England notes. To give an idea of the resistance of these plates we will quote the following lines from the memoir in which he describes the methods employed for this reproduction.

[1] For some years past nickel has sometimes been substituted for copper in making these engravings. As nickel is three times as tough as copper, a deposit of three or four tenths of a millimetre of this metal will replace a deposit of copper of one millimetre in thickness. To this advantage must be added the low price of nickel; this application is used by Boudreaux, Christofle, and Lionnet, and it is employed also as a protective coating on a great number of industrial and scientific machines. More often a copper cliché, deposited as above, is hardened at the surface by a thin deposit of nickel or of iron.

"The electro-deposited copper," he says, "is so hard, that it is scarcely possible to assign a limit beyond which it will be useless; and for the *Times* newspaper it is said that a mould of this kind has already furnished twenty millions of copies without being worn out. At present we have not reached the limit of the duration of electro-moulds for the printing of bank notes, and already more than a million have been printed without any sensible effect."

In France Hulot has also employed electrotyping since 1848 for the reproduction and printing of bank notes, and also for the figures of playing cards.

If electrotyping renders great services in printing engravings of various kinds, it is not less useful in the corrections of engraved plates: for example, in the introduction of fresh details in geographical or topographical maps. These modifications are indispensable in great publications like that of the staff-officers' map of France or the Ordnance Survey of England: the rectification of roads, addition of new roads, railroads, canals, industrial works, &c., was formerly only possible by the method of retouching, which risked spoiling the plate.

M. Georges has designed a method of correction by which these grave inconveniences are avoided. The parts to be modified are taken out with an erasing knife; then taking the necessary precautions, a deposit of copper is carefully substituted by means of electroplating. Then it is carefully planed, and a proof taken; where the parts to be modified come out white, the designers insert new lines, which, transferred to the plate, are then given to the engraver.

It is well known how important it is in chromotypography to have clear marks for the printing of plates with different colours. By electrotyping a perfect marking of plates of this kind can be obtained. The French national printing office has thus been able to print in colours several maps, especially the great geological map of France, which is based on the staff-officers' map for all that relates to the topographical part.

But electrotyping not only reproduces plates identical with engraved ones: it has been applied direct to engraving, as in the old method in which copper plates were acted upon with aqua fortis. Only now it is not a metallic deposit that is wanted, and the plate on which the design to be reproduced is traced, instead of being placed in the bath at the negative pole, is treated as a soluble anode. The

surface being covered with a thin layer of insulating varnish, and the design traced with a point, having laid bare the metal, this is attacked by the electrolytic action; it penetrates in the same way as aqua fortis, and the engraving is made without the operator having to fear the unwholesome action of nitrous fumes.

The methods of Dulos, Gillot, and Garnier, for engraving in relief on copper and zinc, are also based, in part, on electrotyping; but the details of the operations necessitated by these methods are too minute for us to produce here: they would also take us away from our subject.

We must now say a few words about the applications of electrotyping to the reproduction of objects in relief—busts, statues, vases, capitals and other architectural ornaments.

The principle is always the same, but the reproduction of large pieces offered at first difficulties which have now been happily surmounted. Above all it was necessary to avoid inequality of thickness in the deposits in the different parts of the mould, and at the same time to obtain everywhere sufficient thickness to give to the object reproduced a certain solidity. We will suppose that a mould of a statue has been taken, and that its parts have been united so as to form the hollow which the model occupied before the moulding. The question is to obtain, over the whole of the interior, an equal and regular deposit of copper. First a soluble anode was employed, which was placed inside the mould, but the rapid solution of this anode gave an unequal and insufficient deposit. Lenoir proposed to employ an insoluble anode, consisting of platinum wires, surrounding all parts of the mould without touching it. Some crystals of sulphate of copper, inclosed in a gutta-percha bag pierced with holes, were to furnish the copper necessary for strengthening the solution as the deposit weakened it; but this was found to be a costly method, and only applicable to small objects.

Planté tried replacing the platinum by lead: he introduced into the mould a core of lead pierced with holes, reproducing roughly the form of the mould, a little smaller, so as to leave a suitable distance between the core and the inner sides.

Fig. 557 shows one half of a mould which has been used for the electrolytic reproduction of the vase of Figure 558, and indicates how the core of lead we have mentioned is placed. Thanks to this

method the moulding of the best and grandest works in statuary has become possible: statues six feet high, and even some fourteen feet high, for the hall of the Opera in Paris, were moulded by electricity with a perfection which the ancient art of casting cannot surpass. A statue twenty-nine feet in height, weighing 7,700 pounds, has been made in the same way. The thickness of copper is not less than 0·18

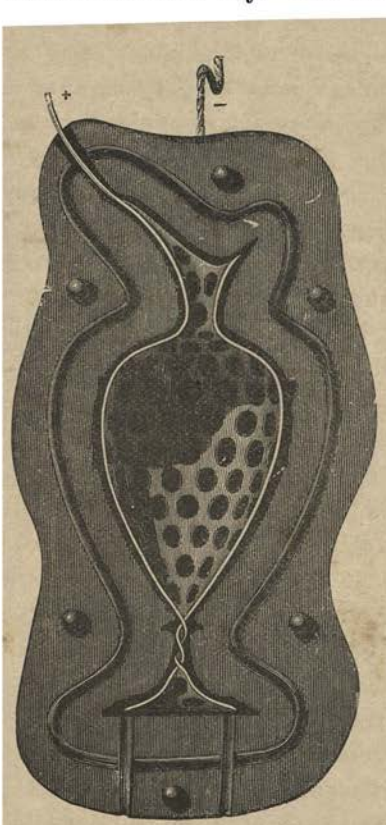

FIG. 557.—Mould for Electrotyping a Round Object.

FIG. 558.—Vase reproduced by Electrotyping.

inch, but it took two months and a half to finish the operation. These remarkable works were executed by the great house of Christofle and Co. We owe to Oudry the electrolytic reproduction in copper of the bas-reliefs on Trajan's column: these bas-reliefs, 600 in number, have each on an average a surface of one square yard. We see, by the importance of this work, that the art of electroplating, so

remarkable for the faithfulness and perfection of its productions, has become, in the hands of our scientists and our workmen, a true and great industry.

§ 4.—*Electro-chemistry.—Galvanic Gilding and Plating.*

The principles on which the methods of gilding and plating are based, and generally the disposition of any metal on the surface of an object in a thin adherent layer, are the same as those of electrotyping. Use is always made of the electrolytic property of a voltaic current, which in traversing a solution of gold or silver, &c., decomposes it, and transfers the metal to the negative pole. But, the principle being known, there were still practical difficulties to overcome: the conditions of adherence of the deposit must be determined, the best composition for the bath must be found, and the best mode of preparing the objects to be covered, &c. We have seen that the methods of Elkington and Ruolz were the first that were truly practicable for gilding and plating.

The apparatus employed, whether composite or simple, are the same as we have described in electrotyping, The preparation of the object consists principally in scouring the surface, which must be perfectly clear of all foreign substances. If the object is of bronze, it is annealed at a dark red heat. If it is brass, it is washed in a concentrated solution of soda; but there still always remains a slight layer of oxide which disappears on immersion in an acid bath. If the objects to be gilded or plated are of iron, steel, zinc, or aluminium they must be first covered electrolytically with a thin layer of copper, without which the gold or the silver deposited on the surface will not adhere.

The next process is the preparation of the bath. For gilding this consists of a solution of cyanide of gold in an excess of cyanide of potash; for silver plating the composition is similar; it is a solution of cyanide of silver in an excess of cyanide of potash. But whilst for silver plating you can work at the ordinary temperature, for good gilding it is necessary that the temperature of the bath during the operation should be maintained at 70° Centigrade: at a lower temperature the colour of the deposit is not good. A plate of gold or silver is used for the positive pole, by which the current enters

the solution, and which serves for a soluble anode; the object to be gilded or plated forms the negative pole. As soon as the electrolytic action begins the cyanide of gold decomposes, the gold is carried to the negative pole, where it covers by degrees the whole surface of the object; but the cyanogen on appearing at the positive pole combines there with the gold, and cyanide of gold is reformed, the same in quantity as that which the current has decomposed. The quality of the solution does not change, and this is an essential condition of the operation. The phenomena are just the same in a silver bath. Figures 559 and 560 show how apparatus for gilding or plating are arranged.

A great vat of wood, the inside of which is lined with gutta-percha, holds the solution. The objects are suspended in it by copper hooks

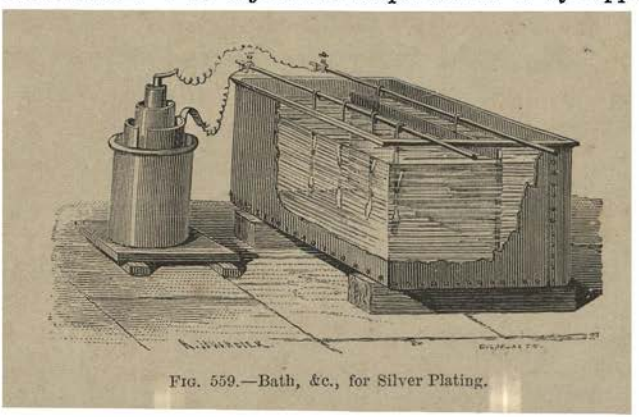

FIG. 559.—Bath, &c., for Silver Plating.

placed on a metal frame, which is joined to the negative pole of the battery. Another frame, insulated from the first, bears some hooks from which are suspended the plates of gold or silver forming the soluble anodes.

The strength of the current must be regulated so as to give a perfectly adherent deposit. The thickness of the layer deposited depends also on the duration of the operation. By weighing beforehand the pieces prepared for the bath, and weighing them again when they come out, an exact account of the weight of the precious metal deposited can be prepared, and the thickness of the deposit calculated. An apparatus is also employed which automatically regulates the duration of the operation when the weight of the precious metal to be deposited on the objects is determined beforehand. This apparatus,

designed by Roseleur, is only a balance arranged as shown in Figure 561. On the left is the electrolytic apparatus placed under the beam, so that the objects to be gilded or plated are supported by it whilst they are in the bath. A horizontal rod, fixed to the column of the balance, bears at one end the soluble anode which is plunged into the bath, and communicates at the other end with the positive pole of the battery. The other end of the beam bears a double scale pan. In the upper part a weight is placed which produces equilibrium, and maintains the beam horizontal. In this position the current does not

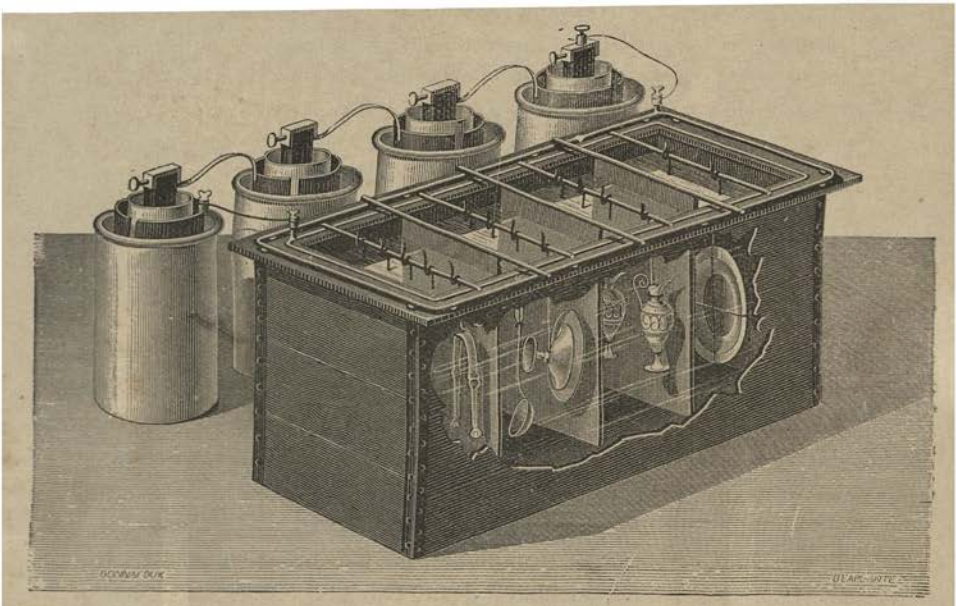

FIG. 560.—Apparatus for Gold or Silver Plating.

pass, provided the bars bearing the objects which ought to form the negative electrode do not communicate with the battery. The weights representing the quantity of the precious metal that is to be deposited on the immersed objects are then placed in the lower pan of the balance and the equilibrium is disturbed, the beam inclines towards the right and a metal point with which it is furnished plunges into a cup filled with mercury and connected to the negative pole of the battery; the circuit is thus closed and the deposition begins.

The operation continues, without watching, so long as the weight

of the deposit does not exceed the weight determined, but immediately that limit is passed, equilibrium is re-established, the mercury contact is broken, and the current is interrupted.

We shall not enter into the purely technical operations which follow the deposition of the layer of gold, or silver, on the objects,

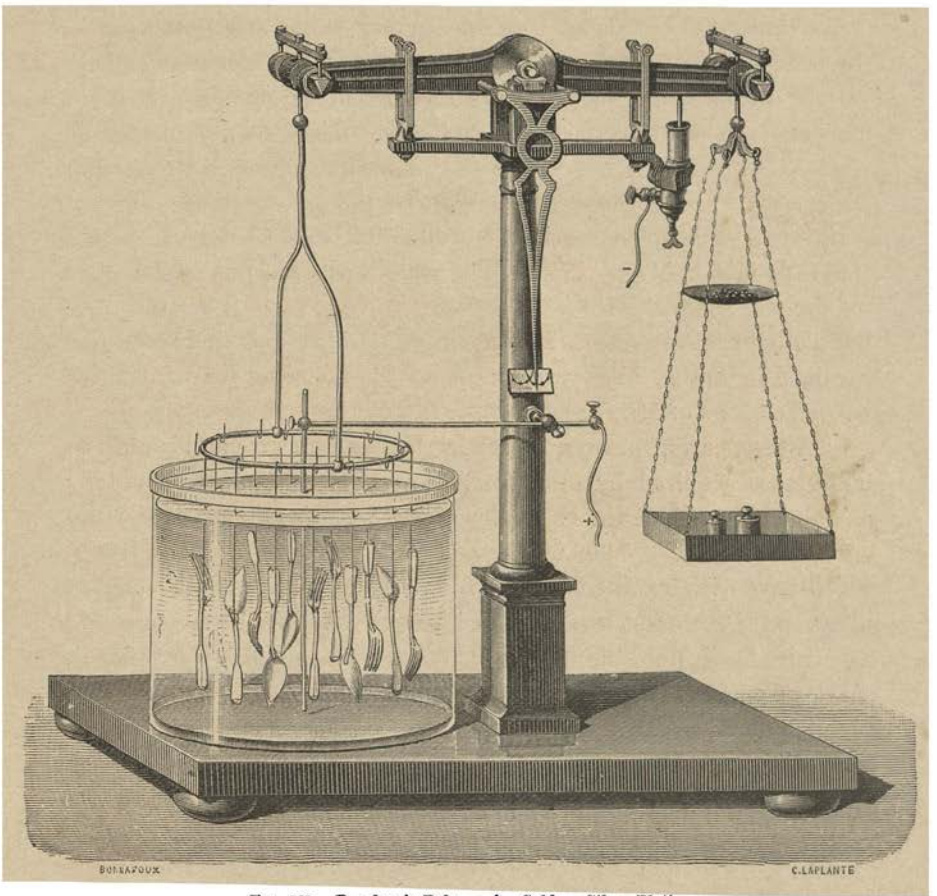

FIG. 561.—Roseleur's Balance for Gold or Silver Plating.

after they are taken out of the bath. We will only say that the dull colour of this layer is rendered brilliant by a scratch brush, and by burnishing, that is, by rubbing the parts which ought to be polished, with a brush made of brass, which is rotated rapidly, and then with hard stones, or pieces of steel mounted on handles. The brilliancy of

the plated objects is obtained at once, by placing in the bath, during the operation, a very small quantity of sulphide of silver. This method was invented by Planté.

The electro-chemical method of plating and gilding is now everywhere applied, and on a large scale; it allows of the introduction into the most modest households of a luxury of good alloy, which is at the same time a help to cleanliness, since many common objects acquire, by being clothed with the precious metal with which electro-chemistry covers them, the valuable property of silver or gold, that is, unchangeableness of surface. At the same time humanity is benefited thereby, for the giving up of the old methods of gilding with mercury does away with the deleterious influence proceeding from mercurial fumes. And lastly, a considerable quantity of the precious metals, formerly immovable as massive gold ware, has been put into a kind of circulation.

To give an idea of the importance which this industry has attained in France alone, we will quote the following lines from the *Grandes Usines* of M. Turgan:

"A few figures," he says, "taken haphazard, will give an idea of the importance acquired by electrometallurgy in the firm of Christofle and Co., which, since the expiration of Elkington's patents, is not the only one existing. 5,600,000 sets of plate have been plated (1865) which have withdrawn from circulation 73,900 pounds avoirdupois, of silver, worth £268,000 sterling. A like quantity in solid silver would have withdrawn from circulation 2,250,000 pounds of silver, that is, more than £8,000,000. 73,900 pounds of silver at the thickness adopted for the plate, that is, 675 grains per square foot, would cover a surface of 134,000 square yards." These lines were written twenty-five years ago; since then this industry has been still further developed.

Electric gilding and plating are now applied to a multitude of things, for example to carved ornaments with which furniture is decorated. The variety of effects obtained by making what are called reserves, that is by gilding certain parts of objects, silver plating others, employing here green gold, there red gold, &c., allows of the introduction of a richness in the ornamentation of luxurious furniture truly remarkable. As the reserves can be hollowed out as deep as is desired, and filled with metal of any sort, the richness of which we speak does not exclude solidity.

Gold and silver are not the only metals applied by electricity in adherent layers. Now, it is known how to obtain deposits of platinum, brass, tin, steel, nickel and cobalt, by employing the

FIG. 562.—Artistic Ornamentation of Furniture by Electrolysis.

solutions necessary for these metals. For platinum a solution of the double phosphate of platinum and soda was once used. Iron objects can be tinned in a bath of pyrophosphate of soda, and protochloride of tin. Lead and zinc can also be electrolytically applied.

An important application of electro-plating is that which consists of covering with steel, plates engraved on copper. The surface of these plates acquires thus a hardness which preserves them, during printing, from any alteration. As soon as the thin covering of steel thus deposited, is worn, and the red tint of the plate underneath becomes visible, a fresh steel covering prevents any further alteration.

To finish this summary of the applications of the electrolytic properties of currents, we will mention a recent one, based on the

FIG. 563.—M. Oudry's Workshop for Copper Plating.

same methods, and which in the hands of the inventor, M. Oudry, has been considerably developed. By this method objects of large dimensions, vases, statues, candelabras, &c., are covered with copper. Among the practical difficulties to be conquered, we shall only mention here that which concerns the fundamental operation, that is, the adherence of the deposit of copper on the pieces, which, because of their size do not allow of their being prepared with the same minute care as smaller gold or silver objects. Simply to cover the surface with a layer of plumbago was found to be insufficient. The acid of the

baths attacked the metal surfaces before the deposit had received the necessary thickness. M. Oudry covered them first with an insulating plaster, unattacked by acids, which is applied with a brush, after cleaning, and retouching with the file and the graving tool any parts of the ornamentation that needed it. This plaster, chiefly of benzine, being dry, the piece is covered outside with plumbago, and recovered with an earthy non-conducting paste, in all places where the copper is not to be applied. Then it is plunged into one of the great tubs which contain the baths (Fig. 563). At the end of five or six hours the thickness of the deposit has reached a twenty-fifth of an inch, and the operation is finished. It only remains to give to the copper the appearance of bronze, which is done by rubbing the surface with a brush dipped in a solution of acetate of copper and ammonia.

The lamp-posts of the city of Paris, the monumental fountains of the Place Louvois, and the Place de la Concorde, the exterior gates of the Opera House, and a great many metallic ornaments of architecture, have been covered with copper by this means, which substitutes beautiful and durable objects for the old iron models, which could not be preserved from rust and destruction by painting. Electrometallurgic industry, by the services of all kinds that it is able to render to other arts, has doubtless a great future before it.

§ 5.—*Application of Electrolysis to the Rectification of Alcohols, and to Metallurgy.*

An important business, that of the manufacture of alcohol, seems likely to profit greatly by the electrolytic properties of electric currents in the rectification of alcohols of bad flavour. According to Naudin, these alcohols owe their bad smell and taste to compositions, principally aldehydes, which are formed during fermentation and distillation, and these impurities, as their name indicates, are only incomplete alcohols, dehydrogenated alcohols. The methods used to transform badly flavoured brandies into good alcohols, that is, alcohols having neither smell nor taste foreign to them, are various; rectification and concentration, the employment of solvents and absorbents, in short, various chemical reactions.

Naudin proposed purifying the crude liquids by electric currents;

the decomposition of the water which they contain furnishes hydrogen, which, carried on to the aldehydes, transforms them into alcohols The method employed consists in putting the crude liquids in contact with a battery constructed of shreds or plates of zinc, at the surface of which a chemical precipitation of copper is obtained in an aqueous solution of sulphate of copper. A current of warm water, circulating in a worm, maintains in the tub, which contains the liquids, a suitable temperature of about 25° Centigrade.

This operation, though sufficient for alcohols made from the distillation of maize, is not so for the crude liquids made from beetroot, or brandy. In this latter case, Naudin passes the liquids, already treated as we have summarily described, into an electrolyser, worked with a current from a magneto-electric machine. Thanks to these new methods, a return of from forty-five to eighty-five per cent. of merchantable alcohol is possible. Naudin's method of rectifying alcohols by electricity has been used for some time with success at the distillery of Bapaume-les-Rouen, where, in one season only, 700,000 litres of crude alcohol from maize and beetroot have been thus treated.

A German, Eisenmann of Berlin, showed last year a model of an apparatus by the aid of which he purifies alcohols by means of ozone, which is oxygen rendered more active than ordinary oxygen by electricity.

He prepares the ozone by passing an electric current into a glass tube traversed by a current of air. Then, by the aid of a jet of vapour, he draws out the ozone formed, which then flows into the reservoir containing the alcohol, which is maintained by a worm of hot water at a temperature of 70° Centigrade.

We must point out as an interesting application of the electrolytic properties of currents that which has for its object the treatment of copper and zinc ores, and the extraction of the valuable metal.

When bars of iron are placed in the sulphated waters of copper mines, a quantity of iron equivalent to the copper contained in these liquids is dissolved, and copper is precipitated in a pulverulent state This deposit can be acted upon by means of a battery, but for some years past, instead of this method, where electrolysis already plays a *rôle*, a new and much more advantageous method has been used, which consists of employing dynamo-electric machines.

In the mines of Oker, three of Siemens's machines work day and night, each one clearing ten or twelve basins, and each of them furnishing daily from 550 to 660 pounds of metallic copper. Similar methods have been adopted in the metallurgy of zinc. Letrange submits the ores of zinc, calamine or blende, after an operation which consists in transforming them to sulphates, to the electrolytic reduction produced by currents from Gramme and Siemens's machines.

Elmore has found that when copper and other metals are subjected to the mechanical operation of burnishing while they are being deposited from their chemical solutions in the electrolytic bath, the metal so deposited is of extraordinary tenacity and ductility. Copper so deposited is stronger than when manufactured in any other known way. Copper tubes and utensils made in this way on appropriate moulds are better than those manufactured by any other method. It is even proposed to manufacture heavy ordnance in this manner by the electrodeposition of pure iron.

CHAPTER XVI.

VARIOUS APPLICATIONS OF ELECTRICITY.

§ 1.—*Electric Medical Apparatus.*

HAVE we given a description, or only exhausted the list of all the applications of electricity? Much more would be necessary for that; we have been obliged to restrict ourselves to the most important, that is, those which are the most generally adopted. Besides, it must be remembered that our aim has principally been to consider the electro-physical phenomena of different orders, and the laws of their manifestation.

We cannot however finish this book without referring in detail to a certain number of scientific applications which seem destined to be much further developed; such as the employment of electricity in medicine, and for registering apparatus intended for continuous meteorological observations.

It will be understood that it is not our province to express an opinion upon the therapeutic and medical value of electricity. What is incontestable is, that this agent produces physiological effects, sensations more or less vivid, and shocks or nervous shakings which are of use in certain morbid stages of disease, such as partial paralysis, in stimulating into activity muscles which for the time are not under the control of their proper nerve centres. At first discharges of static electricity from a Leyden jar were tried; but, chiefly since the discoveries of Galvani and Volta, the mode of action of electric currents has been studied, and it has been possible to make serious applications of these currents in the treatment of various maladies.

Electro-medical apparatus are sometimes batteries of a particular construction, sometimes induction machines, arranged so as to allow

of employing induced currents of different orders at will, and as required by the case.

Among batteries, Pulvermacher's chain was at one time largely

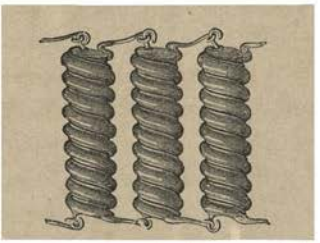

FIG. 564.—Battery Elements of Pulvermacher's Chain.

adopted. Figures 564 and 565 show how this battery is formed, and how it is used. Each cell is composed of a roll of wood, hollowed out in helicoidal grooves. Two metal wires, one of copper, the other

FIG. 565.—Mode of using Pulvermacher's Chain.

of zinc, are rolled round these grooves without touching, and their ends are united, the zinc of one cell to the copper of the next, and so on. The whole forms a sort of chain terminated by two handles, which the invalid holds in his hand, as shown in Fig 565.

To use the chain, it is plunged into a vase containing vinegar and water: the wood absorbs the liquid; the chemical action of the acid on the zinc produces the current, the circuit of which is completed through the limbs and body of the experimenter.

When a shock is necessary the current must be interrupted, and an ingenious arrangement is used to produce successive interruptions. One of the handles contains, inside it, some rackwork which moves a wheel, one tooth of which presses a spring, at each turn. The contact of the battery with the side of the handle is broken at that moment, and the current is interrupted. The rapidity of the interruptions can be regulated, and the shocks rendered more or less frequent.

Electrical treatment, however, should never be resorted to, save under the direct prescription of a regularly qualified medical adviser. Incalculable harm has been done, not only to individuals but to the reputation of electrical science by the nefarious practices of ignorant self-styled medical electricians.

The various kinds of electro-medical induction apparatus are not distinguished from each other by their effects; but they may be classed, according to Le Rouse, in two categories, distinguished from one another by the nature of the original energy expended. In the first, he places all apparatus in which mechanical energy is spent to produce an induced current which is used directly in its own circuit or is employed to induce another current in a neighbouring one. The induced current depends upon the relative movement of a closed circuit and a magnet: the machines are called magneto-electric machines. In the second class of apparatus the current is generated by electro-chemical action, and is used directly, or as before, is employed to induce a current in a neighbouring circuit, and Le Rouse calls these rhéo-electric apparatus. Pixii's and Clarke's apparatus belong to the first class; Ruhmkorff's coil to the second. In Fig 566 is a portable apparatus of this latter kind, which is chiefly used in civil practice.

The generating battery of electricity is formed of two bisulphate of mercury cells, seen to the right of the figure. The current is thrown into a double coil, and the induced current then passes through the wires to two terminals which are seen in the box, and which the experimenter takes in each hand. The interruptions of the primary

current are produced by a Neef's interrupter. The graduation of the energy of the current, and consequently that of the shocks, is made in the following way. It will be observed that each coil is enveloped in a covering of copper that can be moved by the aid of a screw outside, so as to increase or diminish at will the length of those parts of the coils covered with this copper sheath. Induced currents are developed in the copper outside the bobbins; and as these currents are in a direction contrary to those which traverse the wires of the coils, they partly neutralize them. The experiment can thus be begun with very feeble currents, which can be gradually increased to the maximum, which occurs when the bobbins are entirely uncovered.

The medical application of electric currents is of course based upon their physiological actions, which are of several sorts. Delicate

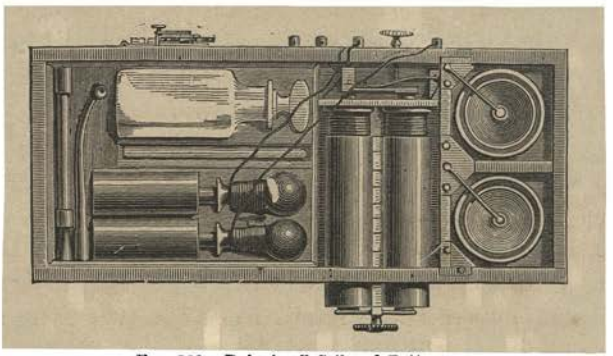

FIG. 566.—Ruhmkorff Coil and Battery.

galvanometric measurements show that every muscle, even when apparently at rest, is the seat of minute electric currents; and when caused to contract suddenly sets up well-marked changes in the electrical condition. Both in nerves and muscles, stimulation sets up electric waves, and in the case of nerves these waves travel, not at the lightning speed of electric currents, but at the usual rate of nerve-impulses, about ninety feet in the second. An electric current when not too strong, tends to produce contraction in the muscular tissue which it traverses. If extremely powerful it may produce permanent injury. The electric resistance of the human body varies greatly in different states of the subject; being much less when the skin is moist than when it is dry. Many deaths have occurred to workmen from accidental contact with unprotected electric wires at

high potentials. Electric pressures of 1,000 volts and upwards have been found capable, when applied to persons having a sufficiently low electrical resistance, to cause the flow of a sufficient current to produce death. In some cases the tissues were actually scorched at the points where the current entered and left the body.

The electrolytic action of continuous currents of electricity has proved, in the hands of Dr. Apostoli, a valuable means of dissipating incipient tumours. More recently Dr. Herries and Mr. N. Lawrence have shown that the subcutaneous injection of certain drugs can be aided and directed by the simultaneous use of electric currents.

Another, and totally distinct surgical application of electricity is to excite an electromagnet of special form used to extract from the eyeball chips of iron or steel which may have entered it; such accidents being not unfrequent in engineering workshops.

Certain surgical operations are directly facilitated by the employment of electricity. For instance, the currents of Planté's secondary cells, by their calorific effects, are very advantageous for cauterizations, in operations lasting only a short time. This electrician especially arranged for this purpose one of his cells in a portable box, furnished at the top with two metal hooks communicating with the poles, and to which the conductors, which end at the cauterizing apparatus, can be fastened. Once charged, the cell has enough energy to execute many successive operations, without recharging it. It is thus that Doctor Onimus was able in 1873 to make cauterizations of the lachrymal gland successively on seven or eight subjects.

For small operations, such as those of dental surgery, Planté has constructed very small secondary cells that can be inclosed in a case, and easily carried in the pocket. These cells are formed so as to cause a platinum wire one-fifth of an inch in diameter to glow for two or three minutes, and a wire of 0·008 inch in diameter for five or six minutes. Doctor Moret has successfully employed these in treating neuralgia by means of transcurrent cauterization, and for instantaneously stopping arterial hemorrhages.

By passing the discharge of a secondary cell through a fine platinum wire bent in a point as shown in Fig 567, the very bright light which results from the incandescence may be utilized for lighting obscure cavities in the human body.

Trouvé constructed an apparatus on this principle which he called

a polyscope. The platinum wires are arranged at the focus of small concave reflectors, spherical or parabolic, and connected with handles to a key which makes or breaks contact with the poles of the cell, as may be required. A resistance coil of platinum wire allows the intensity of the current to be regulated according to the diameter and length of the wire, or according to the use to be made of it.

Probes for examining wounds and for finding and extracting bullets have also been constructed. When the stiletto with which the apparatus is furnished touches the metal, the circuit of a small battery is closed, and an indicator is moved showing the presence of the foreign body. We can only mention here a beautiful application

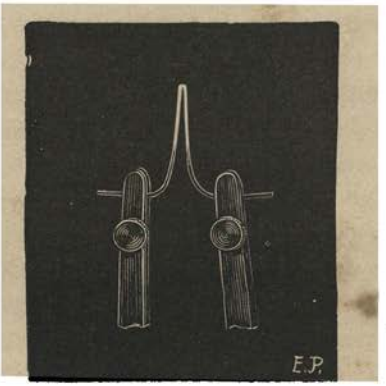

FIG. 567.—Lighting Obscure Cavities.

of the induction balance for finding the place of projectiles in wounds. This interesting application, which does not necessitate the introduction of probes into the body of the patient, but only needs the exterior application of the apparatus, is due to Hughes, Graham Bell, and Hopkins. We have no space to explain Hughes's balance and its method of working in this case, and we can only say that as soon as the apparatus is applied above the point where the bullet lies, a sound is heard in the receiver of a telephone, which is part of the apparatus. The first application of this method took place on the occasion of searching for the ball with which President Garfield was struck.

§ 2.—*Electricity applied to Meteorological Observations.*

Meteorology is a science which, in many respects, is still in its infancy, a fact which is not astonishing to those who consider the infinite complexity of the phenomena the laws of which it proposes to study. The elements of these phenomena are numerous: atmospheric pressure, temperature of the layers of air at different heights, temperature of the ground, and of waters, hygrometry, force and direction of winds, amount of rainfall—these are some of the many quantities required to be observed in the greatest possible number of places on the terrestrial globe, and which demand from the observers a registration of all their variations, with a very laborious and troublesome assiduity. Thus, those who devote themselves to this task are generally obliged to restrict themselves to the observation of instruments at certain pre-arranged hours of the day and night, whence inconvenient gaps in the data inevitably result. For a long time various methods have been tried to remedy the insufficiency of this means of observation, by the invention of instruments which leave an automatic trace of their indications, and thus render immediate intervention of the observer needless. Maximum and minimum thermometers are examples of these kinds of instruments; but they only serve to give indications of singular, isolated elements: they in no way solve the important question of a continuous registration, or one at very short intervals, which would give the curve of the variations of temperature.

The idea of substituting automatic registers for ordinary physical instruments is not new. In 1782 Magellan designed a perpetual meteorograph, but he does not appear to have used it. The principle of this apparatus was purely mechanical, that is, he borrowed from the movement caused by the variations of the elements the force necessary to register the indications. Many kinds of registering apparatus have been, and still are, founded on this principle, which has the merit of simplicity and economy, but which, unfortunately, fails from insufficiency, because of the smallness of the force thus available.

Another system consists in employing photography, that is,

producing on prepared paper, the image, magnified by means of a suitable optical apparatus, of the level of the mercurial columns of the barometer, thermometer, &c.

This system is of course more costly than the mechanical system more especially because in addition to the photographic apparatus, it is necessary to provide clock-work, to cause a continuous movement of the band of paper on which the indications are made.

Lastly there is a third system, which consists in employing electricity as a registering agent: the telegraphic apparatus already described, especially that of the writing or printing systems, suffices to show in what manner electro-magnetic currents may be employed to register meteorological indications. For example, the recorders of the instruments are furnished with needles, which prick an endless roll of paper every time that they are moved by the armatures of electro-magnets, which happens when there is a closing, or an interruption of the electric current; a clock regulates the periods of these closings, at the same time that its wheel work moves the paper forward on which the register is made.

We shall now describe some of the electro-magnetic registering instruments employed in meteorological observations.

The first *anemograph*, constructed in France, was designed by Du Moncel, then modified by Salleron, and afterwards introduced by Secchi into the great meteorographic machine which he exhibited at the Champ de Mars in 1867. The anemometer properly so called is formed of a weathercock, to give the direction of the wind, and a Woltmann mill to indicate its speed. An azimuthal commutator, divided into eight sections insulated from each other, is united, by eight wires, which end at each section, on one side with the same pole of the battery, on the other with the receiving apparatus.

A sliding contact always rests on this commutator, which is directed according to the axle of the weathercock, establishing continuously between this axle and the sections, close metallic contact. The axle being also in communication with the other pole of the battery, the circuit is always closed through the section on which the contact rests, that is, precisely in the direction of the wind. A similar electric communication takes place between the mill, the battery, and the receiving apparatus. This latter is a cylinder which is moved by clock-work, in a uniform manner, so as to make one complete

revolution in twelve hours, and to advance constantly, on its axis, one-twentieth of an inch at each revolution. Eight electro-magnets, the armatures of which are provided with pencils, are placed before

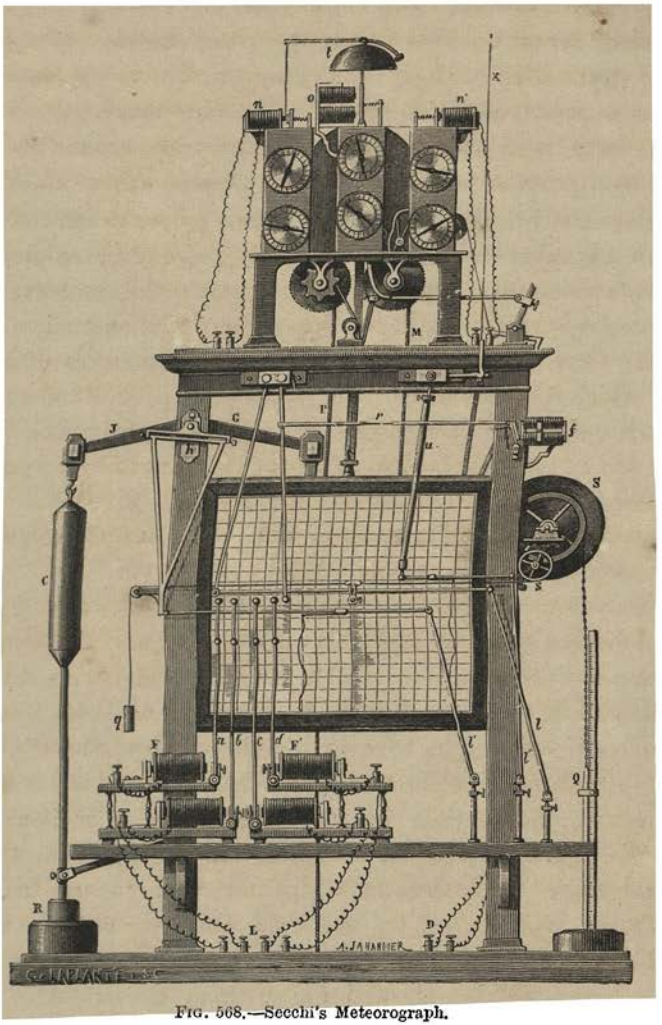

FIG. 568.—Secchi's Meteorograph.

the cylinder, and every time that the circuit of one of them is closed, the corresponding pencil traces on the cylinder, at the surface of which the movement of the armature rests, a line, the length of which indicates the duration of the wind, and at the same time shows

its direction. The total number of turns of the mill is indicated in a similar way, and thus the speed of the wind is regularly registered.

Secchi's meteorograph, represented in Figure 568, has one of its sides surmounted by a clock, and contains a screen on which are registered the indications of the barometer, the dry and wet bulb thermometers, and the hour of the rain. This screen lasts two days and a half, and thus presents very well developed curves, on which it is possible to trace the details of the phenomena, particularly during storms. On the other side of the screen are registered the force and direction of the wind, as well as the indications of the metallic thermograph; and the registrations of the barometer and the rain are repeated there. This screen lasts ten days, and presents a summary of the variations of these elements, which easily permits of their being compared.

In the Belgian section at the Paris International Exhibition of Electricity in 1881 there was a remarkable apparatus for registering meteorological observations—the *Telemeteorograph* of Van Ryssel-berghe, constructed by a mechanical engineer, Schubart: we shall briefly try to give an idea of it.

Figures 569 and 570 represent the two parts of the apparatus. The first shows the arrangement and grouping of the measuring mechanisms, which comprise: 1st, a siphon barometer with tubes of equal diameter; 2nd, a dry bulb thermometer; 3rd, a wet bulb thermometer; 4th, a rain gauge; 5th, an anemometer; 6th, the system indicating the directions of the wind. The second figure represents the registering apparatus, comprising a vertical cylinder, R, on the surface of which is extended and rolled a thin leaf of zinc covered with varnish, and also a graving tool, S, movable along a vertical column; this graving tool, supported by the armature of an electro-magnet, E, has a diamond point which is held back from the cylinder by a spring, but which approaches it, and marks a line on the varnish as soon as the current traverses the electro-magnet. A clock-work movement of great precision, furnished with an isochronous centrifugal regulator with little vanes, is placed under the registering cylinder. This is the motor of the whole mechanism. Every ten minutes the clock-work produces an electric contact and sends a current into a special electro-magnet, and the result is the

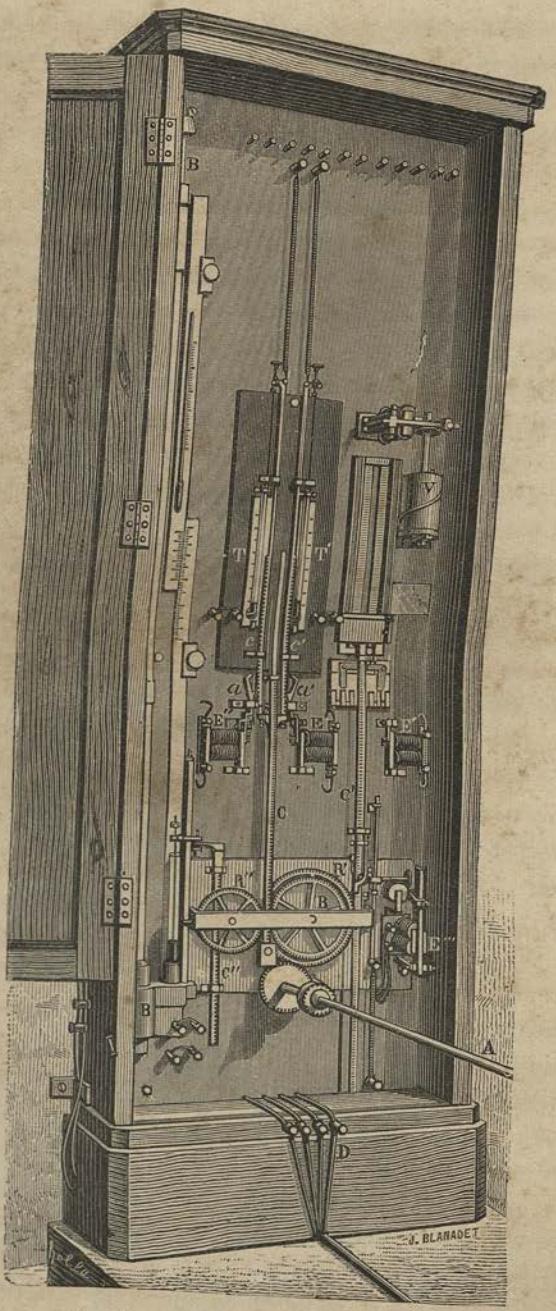

FIG. 569.—Van Rysselberghe's Meteorograph.

disengagement of the registering cylinder. This latter begins then to turn slowly, making an entire rotation in ninety seconds; then it rests. It is during this rotation that the graving tool, S, acts by tracing on the surface of the cylinder the indications which come to

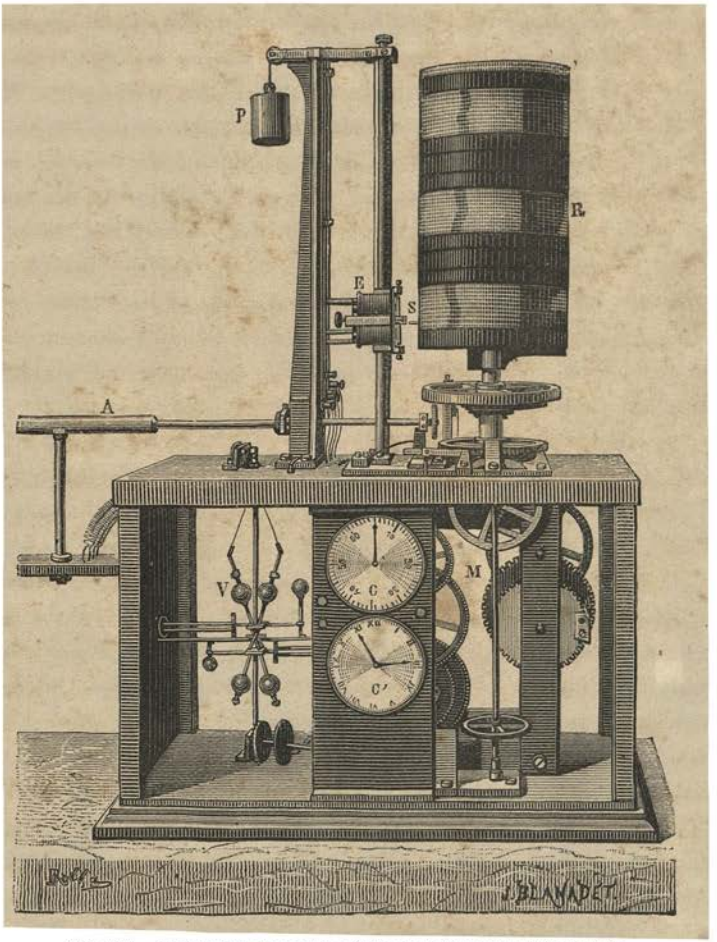

FIG. 570.—Registering Apparatus of Van Rysselberghe's Meteorograph.

it from the measuring apparatus. The real order of this registering is: 1st, the dry bulb thermometer; 2nd, the wet bulb thermometer; 3rd, the rain gauge; 4th, the weathercock; 5th, the barometer; 6th. the speed of the wind. We will try to make clear, by an example,

how this automatic registering is done. First let us consider the barometer.

As soon as the movement of the registering cylinder begins, this movement is transmitted by a system of wheels, and by the rod, A, (Fig. 569) to a toothed wheel, R, and thence to a rack, C'', which supports a platinum wire above the open arm of the siphon barometer. The rack descends, then rises, and the platinum wire after having plunged into the mercury of the barometer, comes out again. Now, from the beginning of the movement of rotation of the registering cylinder, a current passes in the electro-magnet of the tracing point, and this point makes a line on the varnish. As soon as the end of the platinum wire touches the mercury, the current is broken, the graving point is withdrawn and ceases to mark, and this interruption lasts till the rack, having reached the extremity of its course, begins its retrograde movement. Thus the end of the line graven on the cylinder depends on the moment when the interruption of the current takes place, that is, when the end of the platinum wire touches the mercury; its position depends then on the mercury in the little branch of the siphon. Every ten minutes the graving tool descends on the stem which guides it sufficiently for the lines not to be confused. At the end of a given time you thus obtain a series of parallel lines, which are simply the ordinates of a curve, reproducing the variations of the level of the barometer. Mechanisms more or less like these, determine, by means of the closing of an electric current, or its interruption, similar indications for the other meteorological elements. When the sheet of zinc, at the end of a certain time, is entirely filled, a new one is substituted for it, and the used sheets can be engraved by nitric acid and used afterwards for printing.

The reason why the inventor has given this apparatus the name of telemeteorograph is this: a certain number of measuring apparatus may be made to correspond, and placed in stations far from each other; when once synchronism is established between their movements their indications can be separately traced on the same registering apparatus. The meteorograph of Van Rysselberghe has worked for the last eight years at the Observatory at Brussels.

We cannot, for want of space, describe with the necessary details the barographs, thermographs, and other special registering meteorological instruments, the construction of which is based on the use of

electricity.[1] We must be content to have given a general idea of this application, and we finish by insisting on the importance which this method of observation cannot fail to have on the progress of the science. Various systems are used now at the principal meteorological observatories at Kew, Greenwich, Brussels, Rome, Berne, and Paris. When stations of the same kind have been spread over the whole globe, on continents and islands, and when the results of exact and continuous observations, embracing many years, and made with the necessary care, are known, then we may establish more and more exact formulæ, to represent the laws of the movements of the atmosphere, and those other phenomena of which the aërial envelope of the globe is the seat.

Already certain data can be represented in a general way, and they mark the variations of the meteorological elements, according to the places. In the Admiralty Charts are given the lines which mark in direction and intensity the distribution of the magnetism at the surface of the earth. In the same way the isothermal lines of the summer and winter seasons throughout the year may be represented on a diagram.

§ 3.—*Various Applications of Electricity.*

In concluding this necessarily incomplete recital of the applications of which the electric phenomena of different orders are susceptible, we will review some of those which have not found a place amongst the subjects treated in the preceding chapters. Some of these are already old, others are quite new; we need scarcely add that among those that we are obliged to pass over in silence there are some quite as interesting; but we must necessarily be brief. We shall begin with some purely mechanical applications.

The force which is developed in electro-magnets every time that a current passes through the wires of their coils has been utilized in a metallurgical operation which consists in sorting out certain ores, and separating the parts richest in metal from the compounds of

[1] Nevertheless we must mention Theorell's printing meteorograph, which prints every quarter of an hour in ordinary letters, on a band of paper, the indications of the apparatus.

another nature. This process can be followed with metallic oxides, which become magnetic on roasting, or reduction. A machine is used for the purpose invented by a French engineer, Chenot, and which has received the name of the "Electric Sorter." Fig. 571 fully illustrates this apparatus. The hopper on the left is filled with powdered ore which has to be sorted. The ore pours out at the bottom of the hopper on to a metal cloth rolled round two cylinders, and by which it is dragged under three vertical wheels, furnished with electro-magnets fixed on to their circumference. These electro-magnets are connected with a commutator fixed on the common axis of rotation. As the movement carries them to the lower part of the apparatus, they receive the current, and become magnetized. The

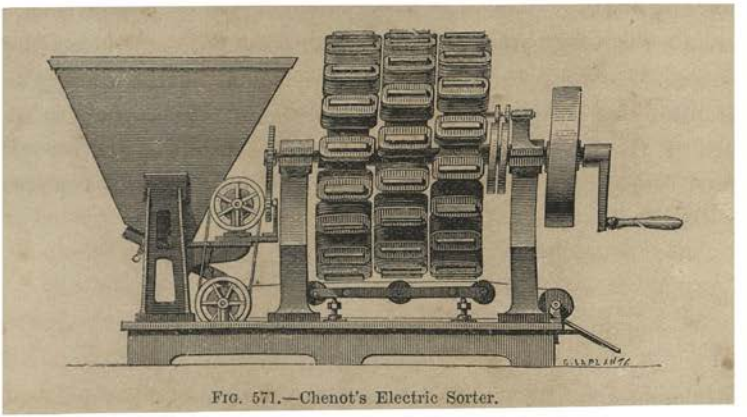

FIG. 571.—Chenot's Electric Sorter.

magnetic part of the ore is alone attracted, and remains in contact with the electro-magnets till the moment when the current, ceasing to animate them, passes into the coils which replace them. Then these parts fall, whilst the non-magnetic fragments are carried behind, into a second hopper. The process of separation thus works continuously.

The same inventor has constructed an electric sorter where there are fixed electro-magnets, constantly animated by the current, which attract the magnetic matters. These are then carried away, as they are separated, by a machine made for the purpose. It is clear that these machines can be used for other things as well, in all works that employ metals, both magnetic and non-magnetic; it may be employed, for example, to separate mixed filings of brass and iron.

Several electric sorters figured at the Exhibition of Electricity in 1881; we shall describe briefly that of Vavin, composed of two bronze cylinders furnished with powerful magnets, before which two systems of rotating brushes move, which detach the attracted filings. The hopper containing the mixed filings is placed above the first cylinder, on the surface of which the filings are spread out by a distributer; thence they pass to the surface of the second cylinder, which finishes the separation begun by the first.

Siemens's electric sorter employs, like that of Chenot, electro-magnets. These electro-magnets, which are very small, and circular, are placed in the interior of a cylinder inclined at 25°, through which the ore that is to be acted upon falls in grains from a hopper. An Archimedean screw moves in the interior and on the axis of the cylinder, and carries the separated magnetic produce into a special reservoir, whilst the rest remains in the lower part of the cylinder and is discharged into another compartment.

Edison's electric sorter, which Fig. 572 represents, is constructed on a principle different from the preceding. The hopper which receives the magnetic ore is placed at the upper part of the machine. The particles of ore in their vertical fall pass before the side of a box in which there is inclosed an electro-magnet separator. The poles of the latter touch this side, so that the separation is made under their influence spontaneously as it were, and without effort. The particles of iron attracted deviate from the vertical, and fall into one of the compartments below, whilst the non-magnetic parts continue their route, and fall into the other compartment.

There was also, in the American section of the same exhibition, a very curious apparatus designed for the separation of bran from flour, without producing any dust. The principle on which this electric sorter is based is this: a cylinder of insulating material (hardened india-rubber) being rubbed by a tufted woollen cushion, becomes electrified, it attracts the lightest particles of the bran of meal or flour, which adhere to it, and accumulate there. The flour falls on to some gauze which sifts it. More than four hundred machines of this kind are used in different parts of the United States.

It is known that carriages, locomotives and tenders of railway trains are provided with mechanisms with which to retard or stop the movement of the train. These mechanisms are called brakes.

An ingenious Frenchman, Achard, proposed to borrow from the energy of the travelling train the power which should by degrees press the skid of the brake against the wheels of the vehicle. He employs the force of attraction of an electro-magnet to disengage the mechanism which acts thus. We give one of the solutions of the problem which he proposed, and solved, for his system is applied on several lines.

The axle of the waggon carries an eccentric, C (Fig. 573), which

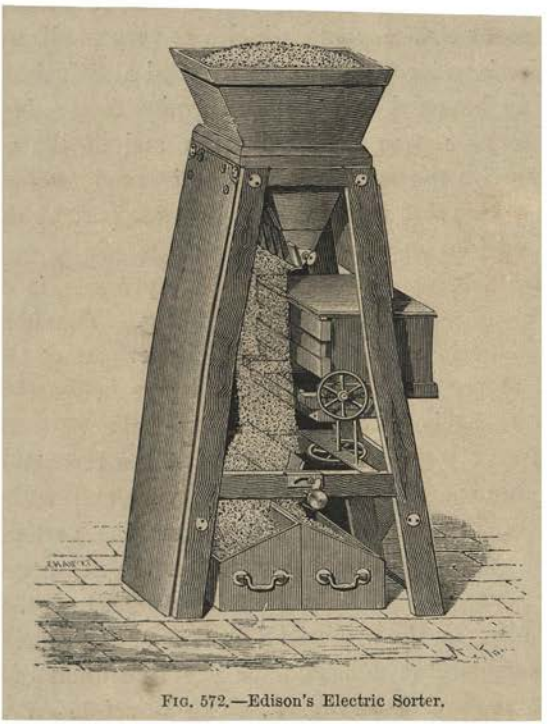

FIG. 572.—Edison's Electric Sorter.

produces a movement of the arm, B, and the oscillation of an axis, O, attached to the arm by a bent lever. This axis itself carries a lever, *e*, the end of which is furnished with a mass of soft iron, *p*, which at each oscillation is placed opposite the poles of an electro-magnet, E. Whilst the current is not passing there is no attraction, and the electro-magnet remains suspended from the rod which carries it. But if the engine-driver, by means of a commutator within his reach, closes the circuit of the battery, immediately the electro-magnet and the

armature are in magnetic contact, and both oscillate together. The suspending rod of the electro-magnet has a catch, K, which is pressed by a spring, *r*, against the toothed wheel, B′. One of the eight teeth of this wheel is thus moved at each oscillation; the wheel turns an eighth part of its circumference, and with it the particular mechanism of the brake. As to the brake itself, this is not the place in which to describe it; it is sufficient for us to show how the engagement and the disengagement are determined by the passage or rupture of a current. The most recent electric brake is that of Professor George Forbes.

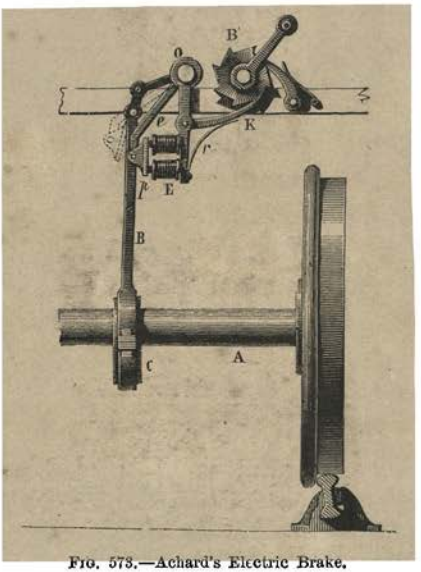

FIG. 573.—Achard's Electric Brake.

Edison's electric pen, shown at work in Fig. 574, is a very ingenious little piece of apparatus, which was one of the first pieces of apparatus used to obtain multiple copies of a manuscript. The lines that are produced by this pen on ordinary paper are not continuous, but consist of a multitude of very fine holes that a steel point makes in touching the paper. This point is at the end of a stem which traverses the tube of the penholder; the stem is oscillating with great rapidity, and when it works without paper, the number of oscillations is not less than 180 per second. At each oscillation, the point passes a very little way out of the end of the tube, just enough to perforate the paper. The

person using it moves it so as to form the lines of the writing, less quickly of course than he would use a pen or an ordinary pencil. But the result is that the paper is riddled with a considerable number of holes, which permit of its being used as a stencil plate. For this purpose a copying press is used, on which a sheet of white paper is placed. The pierced paper, placed on the cover, is brought down. Then by the aid of a roller in a handle, it is covered with a layer of ink which penetrates through the holes, and prints off the writing.

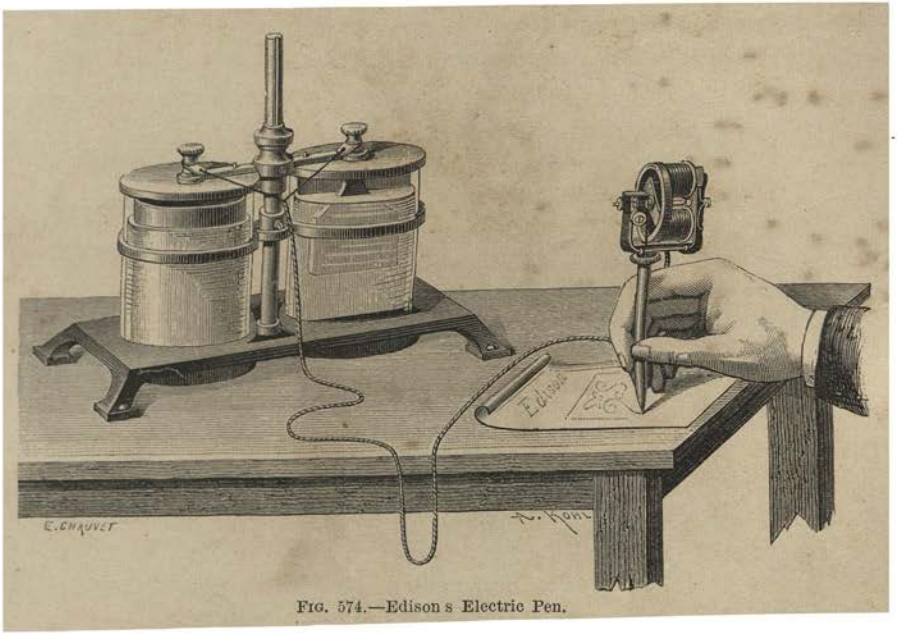

FIG. 574.—Edison s Electric Pen.

A few words however are necessary to explain the electric movement of the perforating stem. This is driven by a very small electro-motor, supported at the upper part of the penholder. The stem terminates in a fork, which incloses an excentric, with three cams mounted on the axis of the motor. On this axis a little plate of soft iron forms the movable armature of a fixed electro-magnet, before which it turns rapidly; a commutator interrupts the current twice during every revolution, just as in the small electric motors that we have already described. As for the electric current which excites the electro-magnet, it is furnished by a bichromate of potash battery

of two cells, placed on the table near the writer. By the aid of a very simple arrangement the electrodes can be put into the liquid, or taken out at will, so as not to exhaust the battery except when the pen is needed.

We shall conclude what we had to say of the electric light and its applications by recalling what we have already said of the advantageous employment that has been made of it in microscopic projections and in its use in photography: in these two cases the electric light

FIG. 575.—Dumas and Benoit's Photo-electric Miner's Lamp.

supplies the absence of the sun. We shall also say a word or two about photo-electric lamps, invented for lighting mines, and which are at the same time, safety lamps. The light produced in these is not that of the voltaic arc: such intensity is not necessary in this case. The induction spark such as is produced in a rarefied medium, or in vacuum, gives a very feeble light, but sufficient nevertheless for lighting mines. It has therefore been utilized to construct safety lamps, of which Fig. 575 illustrates an example.

A capillary tube twisted in a spiral is placed in a glass cylinder, two platinum wires, communicating with an induction coil, are cemented to the two extremities, and it is between them that the successive discharges are made, as in Geissler's tubes. The lamp is attached to a box which incloses the induction apparatus and the battery (Fig. 576).

But a still better system of portable self-contained miner's lamp is one in which is used a small candle-power glow-lamp not requiring a great electromotive force to render it incandescent. Numerous lamps of this kind have been devised by various inventors, and one introduced by Mr. Swan, the inventor of the glow-lamp, is particularly

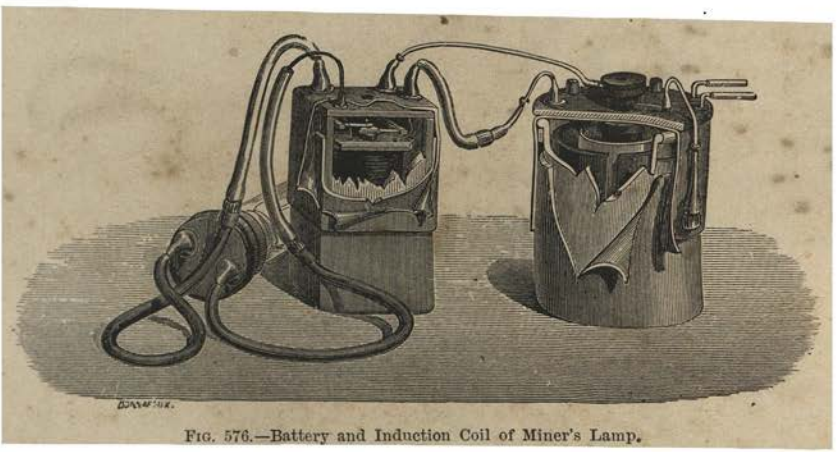

FIG. 576.—Battery and Induction Coil of Miner's Lamp.

ingenious. On account of the explosive nature of the atmosphere in which these lamps are sometimes used, precautions have to be taken against an explosion being caused by the electric spark produced whenever an electric current is broken. Thus the contacts which open and close the lamp circuit, and extinguish or light up the lamp, must either be inclosed permanently in a non-explosive atmosphere not communicating with the outer atmosphere, or be in a perfectly air-tight chamber. Again, since the glass of an ordinary glow-lamp is rather fragile, and since its fracture would lead to the rupture of the filament, producing a spark that would ignite an explosive mixture, the glow-lamp is inclosed in an outer globe of much stouter glass, and the space between the two is filled with an

inert gas such as carbonic acid. As a source of current both primary and secondary batteries have been devised, the great object being to make this part of the apparatus weigh as little as possible, consistent with the maintenance of the necessary current for a period of from eight to ten hours without recharging the battery, either with chemicals in the case of primary batteries, or with a dynamo current in the case of secondary batteries. For instance, a small secondary battery and lamp devised by Mr. Pitkin weighs about eight pounds, and will maintain a light of from four to five candle-power for seven or eight hours without recharging. The lamp itself is mounted either on the top or at the side of the battery, which has handles attached to it, and is in a form convenient for the purposes of the miner.

This system of lighting secures the miners from all danger. In fact the luminous flame is produced in the vacuum without any communication with the air contained in the glass cylinder, and therefore *a fortiori* with the air of the mine: besides, if the apparatus gets broken, the entrance of the air abruptly destroys the spark, and with the extinction of the light all danger of setting fire to the air must disappear.

Gaston Planté designed a very ingenious arrangement of his secondary cells, which permits of their being used in a very convenient form, to obtain light instantaneously, either in laboratories or for domestic use. He has given it the fanciful name of Saturn's Tinder-box; it is a kind of electric lighter. It consists of a small secondary cell, with lead plates well formed, inclosed in a box, the base and sides of which bear a system of conductors arranged so as to make a platinum wire red hot. The wire is fixed beween two pincers placed near the top of the box, and the candlestick is placed between them, so that the incandescence of the platinum immediately lights the wick. To produce this, the simple pressure of the finger on the strip of metal at the base is sufficient. To charge the apparatus, or to maintain it in charge, two contacts placed behind the box are joined to two metal plates of another box, containing a battery of three Daniell or Callaud cells. If it is necessary the battery can be put at a distance and the Saturn's Tinder-box against a little shelf furnished with the necessary contacts, and connected with the battery by hidden conductors.

"With the provision of electricity, which the little secondary cell

incloses, charged at its maximum by the very prolonged passage of the current of the battery, you can," says Planté, " produce even a hundred consecutive incandescences or lights. The result is, that it is not necessary to maintain the secondary cell constantly charging under the action of the battery, and the communicator has for its object to economize the current of this battery, when it is considered that the secondary cell, not having been exhausted by a certain number of successive discharges, can still produce a series of lightings without being recharged.

" The lighting of a candle under the influence of red- or white-hot platinum, is produced without any noise or crackling, and more instantaneously than by any other means. The incandescence

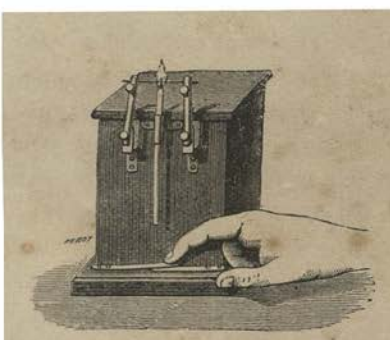

FIG. 577.—Saturn's Lighter.

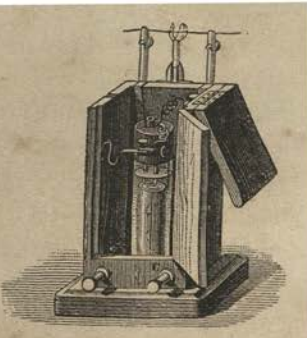

FIG. 578.—Interior of the Saturn's Lighter.

of the platinum wire not modifying in any way the composition of the air, there is no development of smoke, or deleterious or suffocating gas, as is the case with sulphur or chlorates. There is no cause to fear the dangers of fire or poisoning which phosphorus presents. This method of lighting may be considered as very economical; for on one hand, the secondary cell itself demands no expense for keeping up, the lead and the liquid are put in once for all, without ever requiring to be renewed, and on the other hand, to continue the feeble current of the battery destined to charge the secondary cell, it is sufficient to add from time to time some crystals of sulphate of copper, the consumption of which is very small considering the great number of lights that can be obtained."

CHAPTER XVII.

TRANSFORMERS.

DURING the last four or five years the principle of the Ruhmkorff coil which is described and illustrated at p. 364 has received an enormous development for industrial purposes in connection with the transmission of power, especially for lighting purposes, by means of alternating currents of electricity. At different periods from 1877 onwards various proposals were made by inventors and others to utilize the principle of the induction coil in alternate-current distribution; but it is perhaps to the persistent labours of Messrs Gaulard and Gibbs, from the date of their first patent in 1882, that the more recent advances owe their initial impetus. However that may be, under the names of "Secondary Generators," "Converters" or best of all "Transformers," induction coils have now become a widely used and familiar adjunct of the appliances at the disposal of the electrical engineer.

Before entering upon an account of the forms at present in use for the above purposes, it may be well to recapitulate one or two of the fundamental principles underlying the action of the induction coil. It will be remembered that, in the old form of Ruhmkorff coil, a current was sent from one or two cells through a few turns of thick wire wound upon a bobbin and forming what was called the "primary" coil. On the same bobbin was wound a great number of turns of much finer wire to form a "secondary" coil. The instrument was completed by the insertion, in the primary or battery circuit, of an electro-magnetic break or interruptor which rapidly and automatically broke, and then again completed the electrical continuity of that circuit. In this way the current in the primary circuit was periodically interrupted, and at each rise and fall of the current there was,

according to the laws of current-induction, a momentary electromotive impulse in the spirals of the secondary coil, the impulse being in one direction during the rise of the primary current, and in the opposite direction during its fall. The effect was very much increased by inserting a bundle of soft iron wires in the common core of the two coils, and in a large Ruhmkorff coil these electromotive impulses can be made so great that sparks many inches long may be caused to pass in air between the separated ends of the secondary coil, thus demonstrating the existence at those ends of differences of electric pressure amounting to hundreds of thousands of volts. The ratio between the electromotive force impressed on the primary coil by the battery and that developed in the secondary coils depends to a great extent on the ratio of the number of spirals in the two coils, so that the development of enormous electromotive forces in the latter is only limited by considerations of space and difficulties of insulation. On the other hand, had the primary been wound with many turns of fine wire and the secondary with a few turns of thick wire, there would have been a corresponding diminution in the electromotive impulses communicated to the secondary spirals. But according to the law of the "Conservation of Energy" the electrical power developed in the secondary coil cannot exceed the electrical power given by the battery to the primary coil. Now electrical power is the product of two factors, viz. :—electromotive force and current. If therefore one of these increases and the product is not to become any larger the other must be diminished; and therefore, in the old Ruhmkorff coil, although very large electromotive forces are developed in the secondary circuit the current in that circuit is correspondingly small, especially as the total power given out by the battery in the first instance is not very great. But if the coils had been wound differently with a few thick turns for the secondary and a large number of fine turns for the primary, then, although the electromotive forces developed in the secondary would have been very small, they would have generated correspondingly large currents. This method of winding was never employed in the Ruhmkorff coil, because the apparatus was only used for the production of those effects which require large electromotive forces. Indeed it is certain that for a great many years it was not generally known that the usual function of the coil could be so transposed.

It will be noticed that in the Ruhmkorff coil the interruptor is a very vital organ, but that its sole function is to cause the current in the primary circuit to rise and fall. But in the alternate current as generated by a modern alternate current dynamo, such as is illustrated in Fig. 257, we have an electric current which is already automatically rising and falling, and even being reversed, with great rapidity. If therefore the primary spirals of a Ruhmkorff coil be inserted in the circuit of such a machine, the interruptor and its adjuncts become not only unnecessary but superfluous, their place being supplied by the varying magneto-electric inductions taking place in the armature of the dynamo. The construction of the induction coil thus becomes greatly simplified, the only essential parts remaining being the primary and secondary coils with their terminals, and the iron core or circuit for increasing the electro-magnetic effects. Such a modified induction coil is now known as a "Transformer" for the simple reason that its function is to 'transform' small currents at high electromotive forces into large currents at low electromotive forces or *vice versâ*, the product of electromotive force and current being somewhat less after transformation than before, because of certain unavoidable losses due to magnetic viscosity and other causes.

We shall now describe very briefly one or two of these modified induction coils, and then indicate their uses in alternate current distribution. These coils may be divided into two classes known respectively as "closed-circuit" and "open-circuit" transformers, according as to whether the iron of the core forms a continuous magnetic circuit or a discontinuous one. As a matter of fact both these types were evolved in the early days of electro-magnetic discovery as will be seen by reference to Fig. 579, in which No. 1 represents the first induction coil ever made, and is reproduced from Faraday's original paper in which he announced the discovery of magneto-electricity in 1831. In this transformer the iron core forms a closed magnetic circuit which carries the magnetic lines set up by the primary coil to be threaded through the spirals of the secondary without those lines passing through the air at all. The number of windings on both primary and secondary coils were about equal. No. 2 shows a form introduced by Masson and Ritchie in 1842, and which was the forerunner of the Ruhmkorff coil. In it the iron core is a bundle of straight iron wires, and when these wires are magnetized by the current in the primary, the magnetic

lines pass out at one end and have to find their way back to the other end through the air. The magnetic circuit thus consists partly of iron and partly of air and non-magnetic materials, and this is what is known as an "open magnetic circuit." In all modern transformers it is necessary to follow Masson and Ritchie's examples in subdividing the mass of the iron core, because iron is a good conductor of electricity, and therefore if we had large masses of solid iron in the neighbourhood of the primary spirals, secondary induction currents would flow in closed circuits within the mass of the iron as well as in the copper spirals of the secondary coil. These currents would simply heat the iron, and the heat so produced would be so much energy wasted. This is prevented by subdividing the iron, and insulating the separate portions in directions at right angles to those in which these parasitic

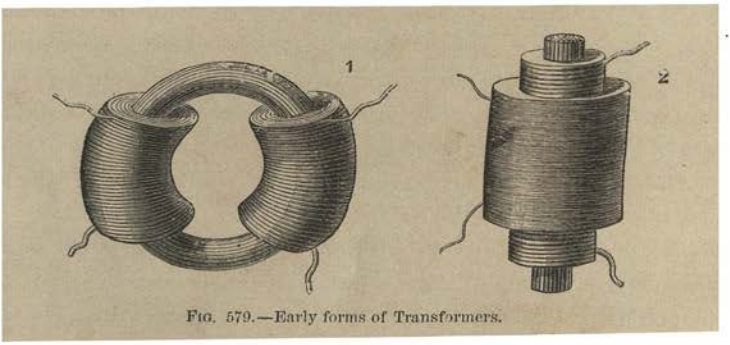

FIG. 579.—Early forms of Transformers.

currents tend to flow, that is to say, the iron must be laminated at right angles to the direction of the currents in the primary spirals.

The well-known Mordey alternating transformer is illustrated in Figs. 581, and 582. Fig. 580 shows the form of the iron magnetic circuit of the transformer, which is built up of rectangles of sheet iron, out of each of which a smaller rectangle has been removed by stamping. The small rectangle thus removed is turned through a right angle and laid across the opening and sides of the larger one. In this way a great number of large and small rectangles placed together alternately and with layers of paper between them for insulation, form the channels which contain the primary and secondary coils of the transformer. Fig. 581 which represents a cross section of the transformer, shows the relative space occupied by the thick and fine wire coils. These coils are, of course, placed in position first

and then the iron circuit is built up round them, the large rectangles being slipped over the coils and the small ones threaded through them. The whole is then mounted in a suitable framework, and the

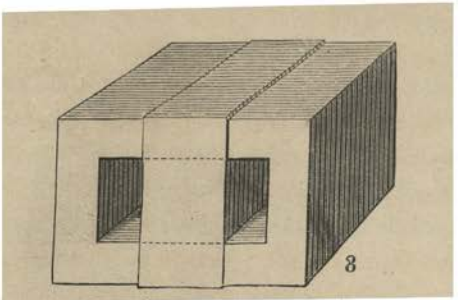

FIG. 580.—Magnetic Current of the Mordey Transformer.

terminals of the coils connected to properly insulated binding screws. The completed transformer is illustrated in Fig. 582, in which two patterns of framework are shown, one suitable for hanging vertically on a wall, the other for standing horizontally on a floor, table, or

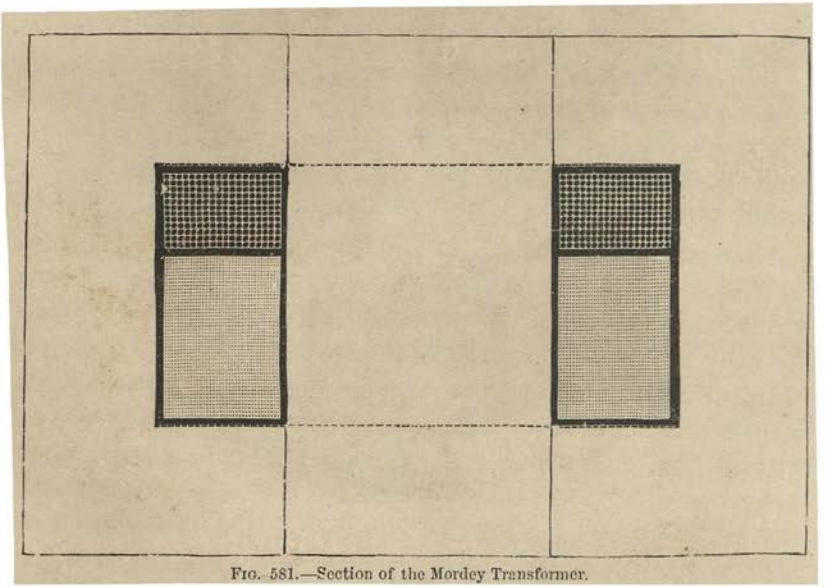

FIG. 581.—Section of the Mordey Transformer.

shelf. Most of the transformers in actual use are closed circuit transformers, and differ from the Mordey transformer only in details.

The original Gaulard & Gibbs' Secondary Generator, patented in

1884, was an open circuit transformer, but it is now quite obsolete, and we shall therefore describe instead Swinburne's "Hedgehog" transformer, which is the only open circuit transformer at present

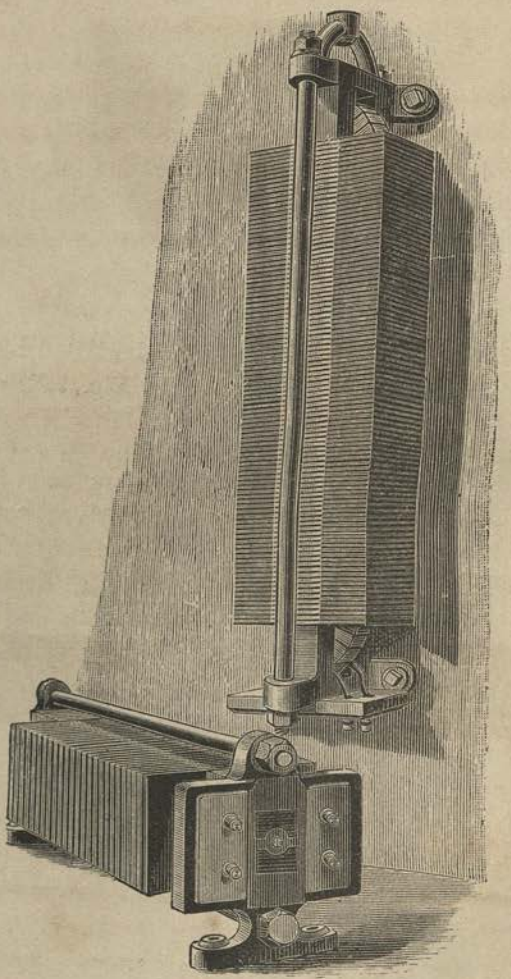

FIG. 582.—The Mordey Transformer.

commercially before the public. Fig. 584 shows the transformer without its case, and Fig. 583 shows the complete transformer inclosed in the case which is rendered necessary by the Board of Trade regulations. The core of this transformer consists of a bundle

of stout iron wire considerably longer than the coils which surround them, and with their ends separated and bent so as to completely hide the end flanges of the coils with a projecting forest of stiff iron bristles. These iron bristles can be seen projecting in Fig. 584. It is from this appearance of the ends of the core that the transformer is named the "Hedgehog" by its inventor. Round the core so formed, the primary and secondary coils are wound with several ingenious devices for securing good insulation and maximum mutual induction. The ends of the coils are brought to terminals on the insulating plate seen at the top of Fig. 583, and the whole transformer is then inclosed in an earthenware outer case, because if an

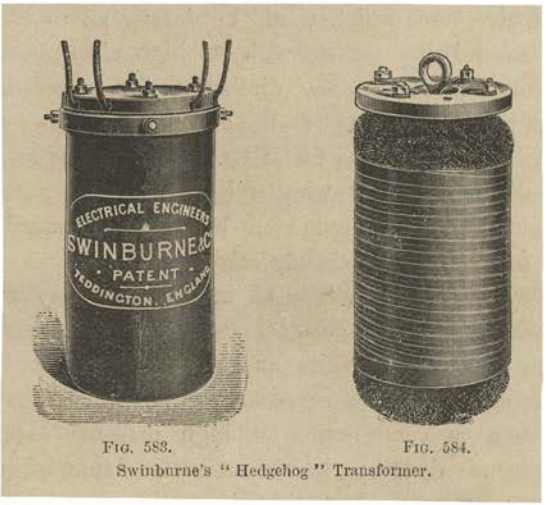

FIG. 583. FIG. 584.

Swinburne's "Hedgehog" Transformer.

iron case were used, as is customary in closed-circuit transformers, this case would form a return path for the magnetic lines in which parasitic currents would be set up and the transformer would become in effect a closed-circuit one. The chief advantages claimed for this type of transformer by the inventor are cheapness of construction and less loss from the effects of magnetic viscosity than in the more common form of closed-current transformer.

We shall now in conclusion point out the advantages obtained by using transformers in alternate-current distributing systems. In the preceding pages of this book it has been shown that the problem of the transmission of power to a distance by means of electric currents is most economically solved by using a comparatively high electro-

motive force and a correspondingly small current. In this way the loss of energy due to the frictional heating of the conductors, and the expenditure of capital that would be necessary if conductors for carrying large currents had to be laid down, are both considerably reduced, whilst a large aggregate amount of power can still be transmitted. But if a high electromotive force is impressed at the generating end of the conductors, a high, though somewhat lower, electromotive force will be delivered at the distant ends. Even if there were no legislative enactments prohibiting such a course it is manifestly inadvisable to place at the disposal or within the reach of persons ignorant of or imperfectly familiar with electrical phenomena an electromotive force which would be dangerous to living beings. The small transmitting current with its high electromotive force is therefore sent through the *fine* wire coils of a transformer, and in no place can the consumer get at the conductor carrying this current without removing insulating materials. He only has at his disposal the terminals of the thick wire coils, the electric pressure, which can be reduced to any required extent by employing suitable windings on the two sets of coils, as already explained.

Secondary batteries can be used in the same way to reduce the electric pressure in direct-current systems, by charging them from high pressure mains in series and discharging them in smaller sections through low pressure consumers' mains. Also with direct current systems a combination of high pressure electric motors with low pressure dynamos, known as motor-dynamos, can be used for the same purpose. But the alternating-transformer has this advantage over both these, that it contains neither corrosive chemicals, nor moving parts. It can therefore be stowed away in any convenient and otherwise useless corner and left to itself. Thus a small box under the pavement can hold a transformer large enough to supply a house, or it can be put in a cellar or cupboard, or even fixed at the top of a telegraph post, this latter position being a favourite place for it in the United States; in this country it would be considered unsightly.

As an illustration of the use of alternating transformers for distribution on a large scale, we may mention the Deptford station of the London Electric Supply Corporation. Here dynamos absorbing about 1500 horse-power generate a current of 100 ampères

at a pressure of 10,000 volts. This current is conducted to sub-stations at Charing Cross and other parts of London, and is passed through the fine wire coils of transformers which reduce the pressure to 2500 volts; at which pressure the electric power is sent into the district distributing mains. To these mains are connected the fine wire coils of the consumers' transformers, where the pressure is still further reduced to the safe figure of 100 volts, at which pressure the electrical power generated some miles away is delivered to the consumer.

APPENDICES.

APPENDIX A.

MODERN VIEWS ABOUT LIGHTNING RODS.

SINCE the publication of the original work of M. Guillemin, though only a few years have elapsed, much has been done to elucidate the problem of protection from lightning. It has been thought better to leave the original chapters of M. Guillemin virtually as they stood in the French edition, and to add as an Appendix a summary of more modern views.

Readers who have perused Chapter II. of the Second Part will not fail to have noticed how the most complete protection was supposed to have been attained by the system of M. Melsens, according to which numerous lightning conductors of copper were carried up the sides of buildings, joining together at the top and furnished with elevated pointed rods, communication being made below to the earth's moist strata by underground extensions.

A few years ago the late Professor Clerk-Maxwell suggested that if a house could be completely inclosed in an external cage or network of metallic wires, it would be protected from lightning without either elevated rods upon its roof or earth connexions. His argument was of course based on experiments such as those narrated in Chapter II. of Book II., relative to the screening action of metallic cages.

In 1887 the editor of this work showed in a paper printed in the *Philosophical Magazine* that iron, owing to its greater resistance to fusion, and its higher specific thermal capacity, as well as its greater cheapness, was preferable to copper as a material for lightning rods. The opinion previously accepted was that copper was preferable to iron simply because of its higher conductivity.

A few weeks later Professor Oliver Lodge, on whose unwearying investigations the whole of the modern views are based, threw a flood of

light upon the problems of protection against thunderstorms. His fundamental point of view is this: that the lightning discharge is of the nature of an enormously rapid oscillation, as the discharge of a Leyden jar is known to be, and is not therefore to be treated as though one was dealing with a simple steady flow of electricity. In fact, Ohm's law, and the ordinary rules about resistances of conductors, which are accurately true for steady currents, are absolutely untrue and misleading if applied to rapidly oscillating discharges.

It was known that the rate at which the oscillations occur in the spark-discharge of a Leyden jar depends not only on the capacity of the jar but on the electric inertia (or impedance) of the conductor through which the discharge is taken. Professor Lodge showed how by increasing the impedance of a circuit, by interposing a stout copper wire rolled up in a coil so as to possess considerable self-inductive action, he could make the time of oscillation of a spark from a Leyden jar so slow as to admit of being separated optically into a number of separate successive sparks passing in opposite directions. Even a straight rod of copper possesses some self-induction: hence there is every reason to believe that in almost every case the spark consists of a set of oscillations.

Now the self-inductive action, or impedance, of a round thick copper wire may be very considerable if the oscillations are very rapid. If a stranded wire of equal section, or a ribbon of copper, is used instead of a round wire, the impedance is much less. Hence thick round wires ought not to be used for lightning-rods.

But a still more important fact is that owing to the same self-inductive action, it is impossible for an electric current to be suddenly started throughout the whole sectional area of a conductor. If the conductor be a thick round wire the current starts in the outside part sooner than in the central part of the section. Hence, when currents are rapidly oscillating, they have not time to start in the central parts before they have to stop in order to try to flow in the other direction.

In brief, rapidly oscillating currents only flow in the skin or surface portions of a round thick copper wire, and do not make use of the central portions. This is quite different from the behaviour of steady currents which flow equally through all parts of the sectional area. Hence, in lightning protectors made of solid rods of copper the central portion of the rod is of no use whatever. An iron rod which was made of the same section would cost about one-seventh part as much, and would answer equally well for all practical purposes, because its impedance would be practically the same. This is of course in direct opposition to the old

notions that iron must be worse than copper because of its lower conductive power. But the fact is that rapidly oscillating currents are governed by the impedance of the conductor, and not by its so-called conductance: hence iron is equally as good as copper, and far cheaper.

In Professor Lodge's researches on the lightning discharge, he experimented with large Leyden jars charged by an influence machine such as those described in Chapter IV. of Book II., and examined the conditions governing the spark. An excellent account of his work is to be found in a lecture by him printed in the *Journal of the Institution of Electrical Engineers* for 1889. He divides the cases of discharge under two heads, (i) Steady Strain and (ii) Impulsive Rush. Under the former category come such cases as when an electrified cloud slowly approaches the earth, or is slowly charged. When this is the case the intervening layers of air, acting as a dielectric, is subjected to a slowly increasing electric strain, and under this action the path of the future discharge is prepared beforehand. In such cases if lightning occurs it will follow a path that can be predicted beforehand with tolerable certainty. Of course the electric charge in the cloud may be dissipated without a spark, by the falling of rain, or by the action of pointed rods, or high trees, or hot columns of air ascending from chimneys, any one of which may set up a gradual silent discharge. But if such a silent discharge is set up, it is probable that if a spark occurs it will follow down the line thus prepared beforehand. Under the second heading of *Impulsive Rush* are included several cases, as when a cloud within striking distance of the earth receives a sudden additional charge from a second cloud sailing above it, this second cloud sparking into the first; or, as when one cloud over another is itself approached by a third cloud and discharges into it; or, thirdly, as when there are two neighbouring clouds capable of influencing one another, for then, if one of them sends a spark to earth, this discharge may suddenly upset the state of equilibrium of the other cloud, and induce in it also a sudden discharge. In all such cases there is a sudden growth of the electric stress on the intervening layer of air, and the discharge occurs with an impulsive rush, along a path not prepared, as it were, beforehand, and not capable of being predicted.

In the former cases, the pointed lightning rod tends to prepare the path, as well as to dissipate the impending charge, by setting up a silent discharge at its point. But in the cases of impulsive rush a pointed conductor would be no better than one that is tipped with a ball.

Owing to the impedance offered by metallic rods, when a flash discharges itself into a conductor, there is a surging of current up and down

at a prodigious rate in the surface layers of the metal, accompanied by a tendency to lateral discharge, sparks being spit off sideways to all neighbouring metallic bodies. In such cases it makes no difference whatever whether the rod be of the highest conducting copper, or of the worst conducting iron: the action is the same. Indeed the worst conducting iron has a positive advantage, for the oscillations and surgings of current die away sooner in those materials that are worse conductors. Of all buildings in the world the Hôtel de Ville at Brussels is the best and most elaborately protected from lightning on M. Melsens' plan. Yet it was struck by lightning and set on fire in 1888, apparently by sparks spit off from the conductors into a horizontal iron bar inside the roof, not connected with any other piece of metal, and lying directly below a stretch of "protecting" lightning rod.

Professor Lodge's researches have led him to certain practical conclusions, of which the following is a summary:

(*a*) All parts of a lightning conductor should be made of one and the same metal, avoiding joints as far as possible, and with as few sharp bends or corners as possible.

(*b*) The use of copper for lightning rods is a needless extravagance. Iron is by far the best metal. Ribbon has a slight advantage over round rod; but ordinary galvanized iron telegraph wire is good enough.

(*c*) The conductor should terminate not merely at the highest point of a building, but be carried to all high points. It is, however, not wise to erect very tall pointed rods projecting several feet above the roof.

(*d*) A good deep earth should be provided independent of gas or water mains.

(*e*) If in any part the conductor goes near a gas or water pipe it is better to connect them metallically than to leave them apart.

(*f*) In ordinary buildings the conductor should be insulated away from the walls so as to lessen the liability of lateral discharge to metal stoves and things inside the house.

(*g*) Connect all external metal work—zinc spouts, iron crest ornaments and the like—to each other, and to earth, but *not* to the lightning conductor.

(*h*) The cheapest way of protecting an ordinary house is to run common galvanized iron telegraph wire up all the corners, along all the ridges and eaves, and over all the chimneys; taking them down to the earth in several places, and at each place burying a load of coke.

(*i*) Over the top of tall chimneys it is well to take a loop or arch of the lightning conductor, made of any stout and durable metal.

APPENDIX B.

ON THE NATURE OF ELECTRICITY.

On page 161 of this work occurs a note by the Editor, pointing out that the modern doctrines of energy have compelled more rational views as to the nature of electrical action than those which were current a few years ago, and are still accepted in France. The reader was urged to treat all electrical actions as matters to be explained by regarding them as the result of the expenditure of energy. Energy must be spent to produce an electrical charge: when the charge is discharged the energy runs down, and in running down does work.

On pp. 184—187 was inserted by the Editor another note pointing out that the occurrence of electrical repulsions, and of the (apparent) electrical attractions, may be explained in accordance with modern views about energy, without having recourse to the two-fluid hypothesis. And in the same note the action known as "influence" was treated in accordance with the same principles.

At the bottom of p. 193 and top of p. 194 was a paragraph relating to the behaviour of dielectric bodies such as air and glass in being subject to a sort of electric stress acting in invisible lines of electric force across the medium.

Further, on p. 383 a paragraph was added expanding Faraday's views as to the magnetic lines of force, and the manner in which they come into play in the magneto-electric method of inducing or generating electric currents.

Again, on p. 371 the Editor added a paragraph upon the celebrated *Electromagnetic Theory of Light*, concerning which it was remarked that it had led him to the conclusion, to which other lines of argument seemed to be converging, that the "ether" in which light is propagated, and which in all probability is the medium through which also all electric and

magnetic actions are propagated in space when they act apparently "at a distance," is nothing else than electricity itself.

All these paragraphs, which the reader will do well once more to peruse, were only brief hints of those modern views as to the nature of electrical phenomena which are now accepted by all the leading physicists in this country.

It were impossible in any small compass to do justice to these recent views, which are the outcome of the experiments of Faraday and of the theories of Maxwell and his followers. Those who desire to obtain a fuller grasp of the subject should procure Professor Oliver Lodge's *Modern Views of Electricity* (published by Macmillan and Co., 1889).

According to these modern views, all really electrical actions go on not in the conducting wires or plates of metal, but in the medium surrounding them. It is a readily-ascertained and well-recognized fact, for example, that when a Leyden jar is "charged," the electric charges reside not on the metal coatings but on the glass. The action on the glass—the electric displacement across it, and stress within it—is the essential fact: the presence of the metal coatings, though useful in the act of charging or discharging, has nothing to do with the fact that the charge exists, and is purely accidental. It is a matter of direct inference that, similarly, when an air-condenser is charged the charges reside on, and affect, the intervening slab of air. The energy stored up potentially in a charged air-condenser has its seat in the electrically-stressed air, not in the metal plates. The presence of the metal plates is a necessary accident of the apparatus, they direct the position of the air-slab but are not themselves charged. At one time this was a hard saying: it is now recognized as simple truth.

Similarly it is now known, though not so directly demonstrable, that in the case of a so-called electric current, the energy-paths lie not in the conducting wires at all, but in the surrounding medium. This was shown in 1884 by Professor Poynting of Birmingham, to be a necessary conclusion from Maxwell's equations of the electro-magnetic field. Shortly afterwards the same discovery was independently made by Mr. Oliver Heaviside of London. When, for example, a copper wire circuit is arranged with a voltaic battery at one part and a thin wire in a distant part to be heated by the current, it is known that the potential energy which is running down as the zinc burns away and combines chemically with the acid is not really transmitted along the copper wire, but flows out from the battery laterally into the surrounding medium in paths that converge at the distant place upon the thin

wire and enter it laterally. The presence of the copper wire directs the flow of energy, but does not actually convey it. True, the conducting wire itself may become warm—but that is simply because of its own imperfect properties: it is itself because of those properties the recipient of a certain amount of energy which travels also into it laterally from the surrounding medium and warms it.

Electricity behaves in fact very much as a liquid of extreme tenuity might be supposed to do. Imagine a liquid, even less compressible than water is, but lighter than water—differing from water as water differs from mercury, only much more so. Water is about $13\frac{1}{2}$ times less dense than mercury: imagine a liquid a million times less dense than water, and even less compressible—at least for rapidly-acting forces. Through such a medium ordinary solid bodies might move at ordinary speeds quite freely, and yet the medium would have properties closely resembling those of hard steel. For example, it might be capable—provided the minute motions were given to it rapidly enough—of transmitting waves.

A medium of some such kind one is forced to admit as existing already in nature. The propagation of light across so-called empty space, with the speed of 185,000 miles per second, or one hundred thousand million feet per second, makes it absolutely necessary to postulate that there exists all through so-called empty space a medium having great rigidity or incompressibility (at least for rapid motions) and relatively an extremely small density. For want of a better term this medium is called *the ether*. Waves of light are simply waves in the ether. But since the speed of light is found to be slower in transparent solids such as glass, and liquids such as water, it is also needful to suppose that in some way the ether can be associated with or attached to the molecules of matter, so that either its density is increased or its rigidity lessened when so associated.

In the year 1886 it was shown by Professor Fitzgerald that whenever an electric discharge is made to oscillate or surge backwards and forwards (as may happen when a condenser is discharged through a conducting wire), a certain portion of the energy of the discharge must be spent in setting up electric waves in the surrounding space. And quite recently, in the year 1888, it was experimentally shown by Professor Hertz that electric waves not only are so set up, but that they travel outwards in the surrounding medium at a speed equal to that of light. Hertz discovered a way of intercepting these electric (or electromagnetic) waves, and of causing them to reproduce electric sparks in an exploring

circuit. These experiments may be said to demonstrate the essential truth of Clerk-Maxwell's famous electromagnetic theory of light: that the waves of light are electric waves, not mechanical waves. But there cannot be electric waves unless there is an electric medium. The medium called "ether" is consequently an electric medium. The state called "electrification" is simply a state of the ether; or rather, the two states called "positive electrification" and "negative electrification" are two states of an opposite kind which result from the expenditure of energy in performing a certain operation upon a portion of the ether, which operation ends in there being a certain portion of the medium displaced, so that at one part of space there is a redundancy, at another part of space a corresponding deficiency of it.

According to these views an electric charge, if moved along in any way, whether mechanically or otherwise, sets up actions laterally to its path, and is capable of producing effects which a charge standing still could never do. In fact, a moving electrified body *ought* to produce similar effects to the so-called current of electricity flowing along a circuit. Faraday explicitly stated that this was his opinion. Maxwell reiterated it. Rowland in 1876 demonstrated the fact by an actual experiment.

But an electric current when circulating in a coiled wire acts as a magnet. Every magnetic action can be precisely imitated by a suitable combination of electric currents circulating in appropriate coils of wire. Is every magnet, then, merely a circulation of electricity? Or a combination of such circulations? This was indeed the hypothesis of Ampère as to the ultimate constitution of magnetic matter. Modern researches go to show that electricity possesses a species of inertia of its own, not indeed quite resembling the inertia of matter. Electricity, when whirling in a vortex, will undoubtedly act on other electric vortices just as one magnet acts on another. This idea is worked out with great elaboration by Professor Lodge in the volume alluded to above. Basing his argument upon a somewhat fanciful speculation of Maxwell's as to the constitution of the medium that would permit the propagation of such vortical motions, Professor Lodge has worked out a most ingenious ideal model of the electrical medium or ether, and has imagined a species of molecular wheel-gearing to account for the lateral transmission of energy in the space outside the wire in which the so-called current is flowing.

Faraday crowned his scientific career by the remarkable discovery of the rotatory action exercised upon the waves of light by a magnet. This discovery, the first glimpse of a connection between electromagnetic and

optical phenomena, has been enlarged in our own time by the further discoveries of Dr. Kerr.

So then though, strictly, it still remains true that we do not know what electricity itself actually is, we are undoubtedly much nearer to a final solution of the problem of its exact nature than we were half a century ago.

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